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Journal
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Devoted to Science and the Mechanic Arts

Vol. 247 MARCH, 1949 No. 3

FRANKLIN, PRIESTLEY AND THE SAMUEL VAUGHAN, JR. MANUSCRIPTS. 1775–1782.

BY

GEORGE E. PETTENGILL.[1]

The Library of The Franklin Institute possesses a small collection of manuscripts formerly belonging to Samuel Vaughan, jr., covering the period 1775–1782.[2] Among the outstanding items are a letter from Joseph Priestley (see cut) describing the making of phosphoric acid and several letters written by Sarah Vaughan, Samuel's mother, in which she makes interesting references to Priestley. One of the draft letters written by Samuel Vaughan, jr. quotes Priestley's opinion on Franklin's method of acquiring a style in writing, and two others contain comments of some length on scientific topics.

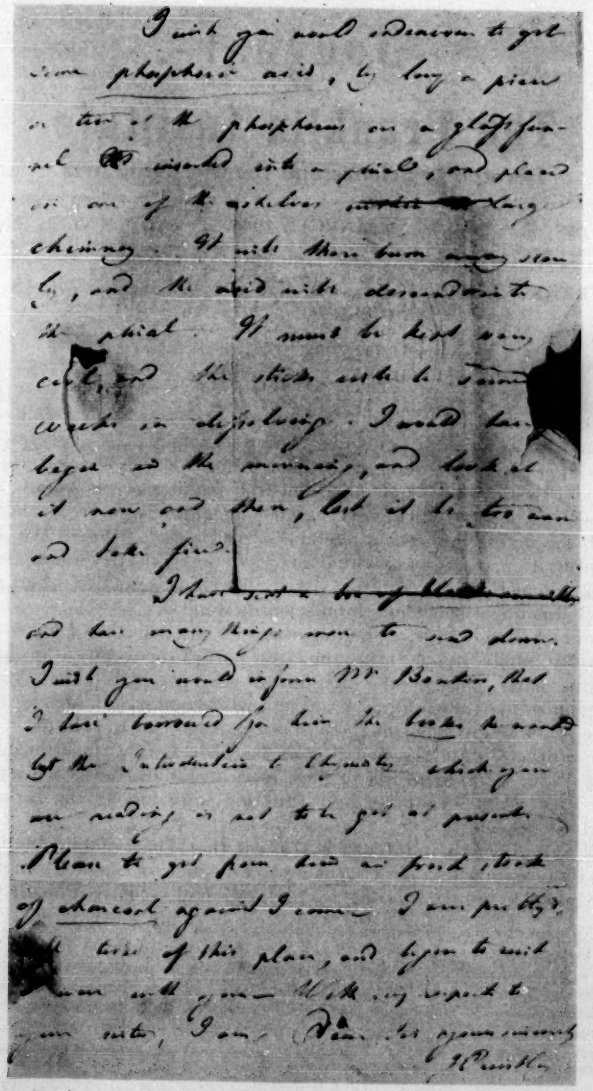
Samuel Vaughan, jr. was a member of a distinguished English and American family, living during the latter part of the eighteenth century and the early part of the nineteenth century. His older brother Benjamin edited an edition of Franklin's works and was an intermediary in the peace negotiations at the end of the American Revolution. Another brother, John, the first of this Vaughan family to settle in the United States, was treasurer of the American Philosophical Society for some fifty years. Franklin and Priestley were among the intimate friends of the family.

Of more immediate interest is the fact that The Franklin Institute owes its inception in a large measure to a nephew of Samuel Vaughan, jr., Samuel Vaughan Merrick. The latter had come to Philadelphia

[1] Assistant Librarian, The Franklin Institute, Philadelphia, Pa.

[2] The collection comprises seventeen notebooks, fifty-seven letters and over fifty other pieces including fragments. The letters include nineteen from his parents, seventeen from his brothers and sisters, one from Dr. Priestley, twenty from friends and acquaintances, and ten draft letters of Samuel Vaughan, jr. The notebooks and other papers include essays, poetry, school notes, mathematical problems, business records and other miscellany.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)



From a letter of Joseph Priestley to Samuel Vaughan, jr., dated April 17, 1782.

V. 19

from Maine to work with his uncle, John Vaughan, and in 1820 he became head of a fire engine manufactory. Feeling a need for mechanical knowledge, Merrick applied for admission to a mechanics institute, was refused, and determined to found his own society. After joining forces with Prof. William H. Keating of the University of Pennsylvania, the two men reached their goal with the formal establishment of The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts in February, 1824. Although no evidence of the association of Samuel Vaughan, jr. with the Institute has been found, his brothers were interested in their nephew's new organization. John was a member. William, and later his nephew Petty, acted as agent for the Institute in England for many years, and Benjamin submitted a drawing of a water wheel for the consideration of the Institute.

Samuel Vaughan, jr. was born June 22, 1762, the fifth surviving son of Samuel Vaughan, 1720–1802. Like all his brothers he attended the famous Dissenting Academy at Warrington. His brothers William and Benjamin had boarded with Priestley while attending the Academy as recorded in the latter's *Memoirs*. Samuel and his sister Rebecca, later the mother of Samuel Vaughan Merrick, also were to have the privilege of living with Doctor Priestley. Some of the letters reveal that they resided some five months in the Priestley home in Birmingham during 1782 studying under his guidance. Samuel was interested in science, but he did not follow a career in that field. After some travel in Europe and America and attention to business for his family and friends, he settled on the family estate, Flamstead, in Jamaica, West Indies. There he apparently spent the remainder of his days. The writer has not as yet been able to verify the date of his death.[3]

Perhaps the most interesting letter among the manuscripts is one which links Franklin, Priestley and the Vaughans. It is a rough draft of a letter from Samuel to his brother Benjamin, soon after the former went to Dr. Priestley's to study:

Fair Hill 16 Jan 82

Dear Brother [4]

I promised giving you in case I went to Nottingham a View of the ground I went on & the prospect before me. The change of situation does not alter the case or leave less room for advice which I have been so frequently indebted to you for & which I have no doubt you will give me if you see any deficiency or opening for improvement—The Doctor [5] for my improvement in composition & forming a Stile has recommended me D[r] Franklin's method of reading a paper every day more or less & afterwards endeavoring to express the same sentiments myself—Addison he admires for his perspicuity but thinks him rather too verbose. Franklin he has as

[3] Certain sources give Dec. 4, 1802 as the date of his death but this is undoubtedly a result of confusion with that of his father.

[4] This is Benjamin, because in a draft letter to his father on the same date, Samuel refers to a letter written to Benjamin for details.

[5] Doctor Priestley is frequently referred to by the name "Doctor" in this correspondence.

great an opinion of yourself [sic] & rather recommends him as he formed himself from Addison & to whom he has added his own excellencies—This Plan I am sensible is a very excellent one & shall adhere to it strictly—Exclusive of this my attention is paid to Chemistry—I have begun with Cavallo's Introduction [6] a Work lately published of great Merit after which shall pursue the same study in a Book late printed at Dijon in 3 Vols in 12ves which for my further improvement in both lines above mentioned D[r] Priestly [sic] advises me to abridge by which time he will have a course of Experiments to pursue which will be a great in sight to the whole—

The time I allot for studies is Eight hours a day beside which intend paying some attention to the Manufacters [sic] but fear I shall not get all the advantages I could wish as where there is not a patent the whole business depends on this proprietor keeping the art a secret & in such a Town as this where each depend on their own *ingenuity* there must be jealouses [sic] however if I know the principle outlines of the trades it will be sufficient as to what end would the numberless variations answer especially as they all depend on some minutiae in Chemistry in which most have but a partial knowledge.

With my best respects & Regards to Mr[s]. V believe me to

Dear brother
Your affectionate B
SV

The reference to "Dr. Franklin's method" poses the question of how Priestley knew about it. Although Franklin refers to it briefly in his *Idea of the English School Sketch'd Out for the Consideration of the Trustees of the Philadelphia Academy*, 1751, he goes into detail only in his *Autobiography*, published subsequently to this letter. The first part of the *Autobiography* was in manuscript during this period and Priestley may have seen it, but it would seem more likely that Franklin told Priestley about it in one of their conversations. If so, it further emphasizes the importance that Franklin attached to the method and Priestley's endorsement is of added interest.

The letter from Priestley to Samuel Vaughan, jr. is of considerable length and is largely devoted to scientific matters:

London 17 Ap[l] 1782

Dear Sir

Yesterday I received both your letters, of the 11 & 13 Ins[t], and am glad to find that your little excursion was so agreeable and instructive to you I shall think myself obliged to my friends for the civilities they shewed you, and I thank you for your attention in procuring me the *specimens* you mention.

As your father does not think to send you abroad till he has some more certain prospect, we thought you had better remain at Birmingham till my return (which, if all be well, will be friday sennight) not come hither for the very little advantage you can derive from my being with you here, especially as care will be taken that you shall have the same advantage whenever you come.

[6] CAVALLO, TIBERIUS. "A Treatise on the Nature and Properties of Air, and Other Permanently Elastic Fluids. To Which Is Prefixed, an Introduction to Chymstry." London, Printed for the Author, 1781.

When you have finished your excursion you cannot do better than keep on in the way you were before, composing something now and then, reading the *Lectures on History*, and proceeding with the *Introduction to Chemistry* [7] & at the same doing any process that you fancy—As to *Phosphorus*, you certainly did very right to make Mr. Reynolds a present of some; and if you like the process, I would have you repeat it; but I think that it will be as well to leave it till my return, as I have got a couple of genuine *Hessian retorts* of Mr. Godfrey,[8] who imports them for the purpose. He sells his phosphorus for *five pounds an ounce*, and says he has 80 ounces now by him. He never makes more than 8 or 9 ounces at a time and uses many retorts in the same fire.

I wish you would endeavor to get some *phosphoric acid*, by lay a piece or two of the phosphorus on a glass funnel inserted into a phial, and placed on one of the shelves within [the] [9] large chimney. It will then burn away slowly, and the acid will descend into the phial. It must be kept very cool, and the sticks will be some weeks in dissolving. I would have [you] begin in the morning, and look at it now and then, lest it be too warm and take fire.

I have sent a box of [black crucibles] and have many things more to send down. I wish you would inform Mr. Benton, that I have borrowed for him the *books* he wanted but the *Introduction to Chymistry* which you are reading is not to be got at present. Please to get from him a fresh stock of *charcoal* against I come—I am pretty well tired of this place, and begin to wish I were with you.—With my respects to your sister, I am, Dear Sir yours sincerely

J. Priestley

Addressed Mr Sam' Vaughan

There are numerous references to Priestley throughout the correspondence. The most interesting of these are found in the letters of Sarah Vaughan. On May 14, 1780 she wrote her son concerning Priestley's health:

Doc Preistley [sic] is now with us in a bad state of health owing to too long a neglect of a complaint that if taken in time would have been easily conquered. they were afraid that the liver itself was diseased but they have now hope that it is only the Gaul Bladder and ducts and by some symptoms fear there may be stones but that is not so alarming as what they first feared. he has long neglected himself and thought the complaints were only temporary and never supposed they would be serious. we expect her in town in a few days and when Fothergill will give leave he returns into the country that is to Calne.[10]

---

[7] This is undoubtedly Cavallo's. See note 6. It contains the following references to phosphorus: p. 146–147 To make Mr. Canton's calcareous phosphorus; p. 148–154 To make Kunckel's phosphorus.

[8] It is not possible to identify Mr. Godfrey definitely but he was probably a son or grandson of Ambrose Godfrey Hanckwitz, 1660–1741, who founded a pharmaceutical firm in London and made phosphorus.

[9] Illegible and mutilated words have been indicated by the use of [ ]. No notice has been taken of words deleted.

[10] The estate of Lord Shelburne for whom Priestley was librarian, 1773–1780.

Again in 1782 Samuel's mother wrote to him as follows: "how does Doc Preistley [sic] health stand we hear that he is but poorly his old complaints returning again. I hope its a false alarm and that he is well. . . ."

These references with their charge of self neglect may well be compared with Priestley's own account of this illness written a few years later:

> And so far have I been from suffering by my application to study, (which however has never been so close or intense as some have imagined) that I have found my health improving from the age of eighteen to the present time; and never have I found myself more free from any disorder than at present. I must, however, except a short time preceding and following my leaving Lord Shelburne, when I laboured under a bilious complaint, in which I was troubled with gall stones, which sometimes gave me exquisite pain. But by confining myself to a vegetable diet, I perfectly recovered; and I have now been so long free from the disorder that I am under no apprehension of its return.[11]

Another letter of Mrs. Vaughan to her son seems almost prophetic in its nature, when one remembers that Joseph Priestley was later forced to leave Birmingham because of riots, of which he was a principal target. Under date of Dec. 11, 1780 she writes:

> I hear Doc Preistley [sic] has an invitation to the meeting at Birmingham. I wonder whether he will accept or not. if he had never wrote he might have preached forever but I am afraid some busy people will disturb the peace of the society by his particular sentiments. this to yourself till we know it [ ] then you may spread it abroad.

The last two letters chronologically in this collection are draft letters from Samuel Vaughan, jr. to Benjamin Vaughan, September 6, 1782 and to Dr. Priestley, September 9.[12] Although the letters cover somewhat the same subjects they are given in extenso because of their considerable attention to scientific matters, typical of those in which cultured men of the time were interested:

> Wanstead 6 Sep^{t} 82
>
> Benj^{n} Vaughan Esq Paris
>
> The present motive in diverting your attention from more important objects, is to request your procuring me *Monnets mineralogy & his Exposition of the Mines* which M^{r} Kirwan[13] has recommended very particu-

[11] PRIESTLEY, JOSEPH. "Memoirs of Dr. Joseph Priestley, to the Year 1795." London, J. Johnson, 1806. p. 102.

[12] These are contained at one end of a blank book. At the other end are twelve pages of algebra with text in shorthand, and there is nothing else in the volume.

[13] Richard Kirwan, 1733–1812, chemist and natural philosopher, lived in London from 1777 to 1787 and became acquainted with Priestley, Cavendish and other leading figures of the day. His *Elements of Mineralogy* published in 1784 was the first systematic work in English on the subject.

larly to me.—If you should have an opportunity of forwarding these, to prevent delays before your own departure, my obligations will be still greater.—

My late Tour into Derbyshire has taken up two months, & in Dr Priestleys & other friends opinion at Birmingham, it was not idly spent.—They advised my drawing out some facts which I mentioned to them, with a view of presenting them to the Royal Society. However since my return to this place, I find from the opinion of Mr Kirwan, that the conclusions from these facts are by no means *novel*. I shall nevertheless draw them out for the satisfaction of my friends at Birmingham, & have heartily wished for your presence to overlook & compare them with specimens which had brought up for that purpose, & from which with other circumstances think that the following conclusions may be drawn.—That the Strata *were* regular altho' now in confusion: that there are *possible* causes for these irregularities, together with some curious facts relative to the Toadstone or supposed Lava: That all the Minerals owe their deposition & form in the Mines to Water: & that these Minerals are to be traced to the Strata superincumbent on that particular one, in which they are found collected into Mines. These particulars are quite clear in my mind, tho the proofs are not perfect from the short time I staid there; the necessity of digesting what I had done before I proceeded, which I had in prospect at the time;—& being less attentive, from a supposition of the country having been already thoroughly explored.—

I went today to Mr Parkers [14] with Mr Kirwan, to see the famous Lens Mr P. has just executed—which was wonderful indeed—Platina has been perfectly melted in 17 Seconds, Iron commenced melting in 2 Seconds, & was perfectly melted in a very few more. Mr Wedgwoods clay used in his late invented pyrometer, was melted to a glass, as was Asbestos &c &c but its powers shall be more particularly acquainted with, next Tuesday, & following days, when am to try its effects on all Derbyshire minerals & earths. —I think you will wish a little jealousy (if nothing else) will induce the Literati here to subscribe & purchase it, as the French Academy have already made proposals for that purpose.

Mr Whitehurst has requested my letting you know the difficulty the Society [15] are under, for want of a Secretary, & their wish of your appointing a Deputy, when at a distance, whose constant residence is in London. I am. . . .

P.S. By letters from John [16]—he was well in June last—his accounts greatly discourage my father & self, 9/a day Boarding & £25 p ct discount for Bills on Europe, will I am afraid exclude every thought of my going to America before a Peace—I beg therefore you would work hard—[17]

---

[14] Mr. W. Parker of Fleet Street, London, made "The most perfect burning lens ever constructed at an expense of 700 l" according to David Brewster in his *Optics*, London, 1831, p. 321–322. Young Vaughan's refererfce to a subscription is of interest as such a plan was tried and failed, the lens being disposed of subsequent to 1802 to a Captain Mackintosh who left it in Pekin. *Rees' Cyclopedia*. Philadelphia, n.d. Vol. 6 under Burning glass.

[15] This may well be the society referred to by John Playfair in his *Journal*: "I was introduced by Mr. B. Vaughan . . . to a chemical society, which meets once a fortnight at the Chapter Coffee-House. Here I met Mr. Whithurst. . . ." Quoted by James Kendall in "Some Eighteenth-Century Chemical Societies" *Endeavor* 1:106–109, July 1942. Mr. Whitehurst is presumably John Whitehurst, 1713–1788, horologer of London.

[16] John Vaughan, a brother, arrived in Philadelphia in the spring of 1782.

[17] Refers to Benjamin Vaughan's part in the peace negotiations with Franklin in Paris during 1782.

Wanstead 9 Sept 82

Revd Dr Priestley Birmingham

We had the pleasure of a letter from John last Saturday, dated in June, when he was well—The account he gives is very discouraging both to my Father & self.—9/a day Boarding & £25 p Cent discount for Bills on Europe, will lengthen my stay in these parts.—The time however will not be lost, while I have such an object as chemistry; & to make this more than a speculative pursuit, my Father thinks I should procure one of Dr Blacks[18] furnaces.—I recollect your considering this as useless, to carry to America: however, as there is very little probability of my going before a Peace, than which nothing seems more uncertain; this should imagine is no longer an objection, unless you can point out a better compendium of instruments for the operations by fire than this furnace & its apendages.—Mr Kirwan wishes also to have one—both which, you would oblige me in requesting Dr Withering[19] to order with particulars as mentioned at the end of this letter.

The Derbyshire papers were finished a fortnight last Wednesday, but as I wished to have Mr Kirwan's opinion, I lent them to him. I hope however to forward them in all next week.

I have seen Mr Parkers Lens, which I believe was not up when you left London,—its effects are really astonishing—Platina was perfectly melted in 17 Secds; & the clay of Mr Wedgwoods Pyrometer was fluid in I believe a shorter time.[20]—I saw Asbestos turned to a Glass & different Irons melted in a few seconds.—A Diamond however, in 18 minutes, was not dissipated as in the Paris experiment: the surface only becoming rough, a crack widening & a few fumes arising.—Tomorrow I carry many derbyshire substances, particularly Toadstones & clays, to try its effects on them.

I beg my best respects to Mrs P., who I hope has benifitted from her late Journey, & the family.—I am, with the greatest respect, Dr P.

Your very sincere & hble servt

One furnace for Mr Kirwan, having the opening longer at Top than Dr Priestleys, to put in Retorts with greater ease.—but if this cannot be, the dimensions must be larger.—
One furnace for SV—of the dimension of Dr P's at least, with any new improvement, & every necessary utensile. The expense of Mr K's is presumed about 3G$

Other items in the collection indicate the Vaughan family's close interest in Franklin. In a draft letter written in January 1779, Samuel requested his brother Benjamin to send on the copy of Franklin's *Vis Inertiae* if the latter did not need it. In an undated paper on "The Advantages of a Regular Method Illustrated with Respect to Writing, Business & Morals" the maxim "there are more fortunes saved, than gain'd" is quoted from "Dr. Franklin's *Poor Richard*." [21] Present also

[18] Probably Joseph Black, 1728–1799, chemist and discoverer of "latent heat."

[19] Probably William Withering, 1741–1799, physician, botanist, mineralogist, who was associated with Priestley in the Lunar Society.

[20] Priestley refers to this under date of Sept. 16, 1782 in a letter to Wedgwood, the famous English potter with whom Priestley had been acquainted for some twenty years.

[21] The writer has been unable to locate this maxim in the Poor Richard almanacs as edited in Paul Leicester Ford "*The Sayings of Poor Richard*" *The Prefaces, Proverbs and Poems of*

is a transcript of the letter to Franklin from Lord Howe on his arrival at Sandy Hook in June 1776 and the former's lengthy reply. This is in many respects a rough copy, apparently showing copyist's errors, and it does not agree with any of four printed versions. It seems to be closest to that used by Benjamin Vaughan in his edition of Franklin's works.

Although it does not fall within the scope of this paper to discuss all the literary or historical material to be found in these manuscripts, a few examples might be cited. In a poem by William Turner [22] "A Poetical Essay on Seeing the Sun Rise from Hill Cliff near Warrington, in the Beginning of Spring, 1778," there is a description of Warrington Academy with some words of praise for Priestley.

> But here, my Muse, assist me yet my muse
> To sing of Academus' sweet retreat.
> Hail, simple Edifice, yet elegant!
> The child of generosity renown'd!
> How beautiful thy spacious halls appear,
> The seat of every Science! What a group
> Of Noble characters is spread abroad
> In each fair Scene of Life . . .
> . . . Here Taylor taught
> Here Willoughby presided, Sedden flourished—
> All these alas! too soon have left the world.
> Here Priestley taught divine Philosophy
> And tho no longer here, yet still exerts
> His clear intentive brain & ready pen,
> To search the road to truth & pull down falsehood.
> And now an Enfield & an Aiken govern.

In the same notebook are some "Characters," poems by "Mrs. B. then Miss A. . .n." [23] Most of these are apparently unpublished and the characters are identified, in contrast to those in her published works. In two of the letters there is reference to a poem sent to Dr. Priestley entitled "Life, Parentage & Education & so forth of—Phlogiston executed at Birmingham by the common executioner of falsehood."

In such a collection of letters of a family prominent in public life one would expect to find numerous allusions to public affairs and such is indeed the case. Because of the Vaughans' property in Jamaica, they were much concerned with the naval aspects of the American Revolution and referred to it frequently. A poignant note occurs in the description [24] which Henry Laurens, jr. gives of his reunion with his

Benjamin Franklin Originally Printed in Poor Richard's Almanacs for 1733–1758. New York, G. P. Putnam's Sons, n.d. The closest seems to be "If you'd be wealthy, think of saving more than of getting." p. 138.

[22] Presumably William Turner, secundus, 1761–1859, a classmate of Samuel Vaughan, jr. at Warrington Academy.

[23] Anna Laetitia Aikin, later Mrs. Rochemont Barbauld, daughter of Dr. John Aikin, who taught at Warrington Academy for a long period.

[24] In a letter to Samuel Vaughan, jr. Jan. 31, 1782.

father on the latter's release from prison where he had been held by the British.

The letters and quotations given here are the highlights from the papers of an eighteenth century youth. In the twentieth century their manner of arrival in The Franklin Institute may only be conjectured. One would like to think that when Samuel went traveling on the continent he entrusted his letters and notebooks to his sister Rebecca and that they eventually descended from her to her son Samuel Vaughan Merrick, who presented them to The Institute. However they came, they have been preserved these many years to add their bit to our knowledge of late eighteenth century science, history and literature.

V.
19

AERODYNAMIC PURSUIT CURVES FOR OVERHEAD ATTACKS.*

BY

G. H. HANDELMAN.[1]

ABSTRACT.

The determination of the proper deflection which the gunner in a bomber should make to defend his plane against a fighter attack during the bombing run necessitates the study of the pursuit curve followed by the fighter plane during such a maneuver. This paper is concerned with the study of the aerodynamic pursuit curve for an overhead attack. The basic assumptions for the problem are discussed in some detail and the corresponding differential equations set up. These have been integrated graphically and the results and conclusions are considered at length. The paper closes with a short discussion of the method of obtaining the basic constants in the problem and a brief description of the graphical technique employed in integrating the basic equations.

1. INTRODUCTION.

A considerable amount of work has been done in the past few years in evaluating and improving methods of aerial gunnery. One of the approaches to the study of these problems, which has been the subject of considerable investigation, is the question of *pursuit curves*. For this purpose, a pursuit curve is defined as the path traced out by some fixed point in a fighter plane (usually the center of gravity) as it attacks a target moving along a specified course. The target most commonly considered is a bomber moving at a constant speed in a straight, horizontal line.

For the purposes of such an analysis, different manners of approach are possible. The theory of the *pure pursuit curve* is based entirely on kinematic considerations. Both fighter and bomber are regarded as points moving with constant speed, the fighter's path being such that the tangent vector (taken to coincide with the axis of the gun bore) is always directed toward the bomber. The resulting curve always lies in a plane. As can be readily seen, this is merely a restatement of the classical "dog and master" problem (1).[2] While this theory leads to comparatively simple mathematical relations, it obviously disregards the following facts: (1) The speeds of the fighter and bomber are by

* This paper is part of a thesis submitted to Brown University in partial fulfillment for the degree of Doctor of Philosophy. It is based upon work performed for the Office of Scientific Research and Development under Contract No. 1066 and was issued in amplified form as Applied Mathematics Panel Report 106.1R by G. H. Handelman and W. Prager.

[1] Assistant Professor of Mathematics, Carnegie Institute of Technology, Pittsburgh, Penna.

[2] The boldface numbers in parentheses refer to the references appended to this paper.

no means negligible as compared with the muzzle velocity of the fighter's gun. Accordingly, the fighter pilot must not aim at the instantaneous position of the bomber but must add a certain lead, which depends on the relative position and on the velocities of both airplanes. (2) The direction of the fighter's velocity varies not only with respect to axes fixed in space, but also with respect to axes fixed in the fighter plane. Since the guns are assumed to be mounted rigidly in the fighter plane, the angle between the velocity vector of the fighter and bore axis of its gun must be taken into account in order to obtain the correct deflection. Aerodynamic theory permits the study of the variation of this angle with time. The theoretical path of the fighter plane is described as a *lead pursuit curve*, an *aerodynamic pursuit curve*, or an *aerodynamic lead pursuit curve* according to whether only (1), only (2), or both (1) and (2) are taken into account.

The present paper is concerned chiefly with the aerodynamic pursuit curve for an overhead attack, that is, an attack in which the entire motion of the fighter is confined to the vertical plane through the straight path of the bomber. The bomber is assumed to be flying along a horizontal straight line at constant speed. The bullet velocity of the fighter's gun is assumed to be very large as compared with the speed of the fighter; consequently, lead is not taken into account. Thus the fighter pilot flies in such a way as to keep the enemy bomber constantly in line with the bore axis of his gun. Since the original report, on which this paper is based, was first issued, a considerable amount of work has been done on this problem and its extensions (2, 3, 4). Particular mention should be made of the very elegant treatment of the three-dimensional aerodynamic, lead-pursuit curve by L. W. Cohen (3). While the problem considered here is more restricted than the aerodynamic, lead pursuit curve, or even the three dimensional aerodynamic pursuit curve, it illustrates, in a relatively simple manner, many of the essential features which are present in the more complicated theories. In particular, it presents many of the major difficulties which arise when aerodynamic forces are considered and gives an estimate of the corrections which must be made on the corresponding pure pursuit curve.

2. EQUATIONS OF MOTION.

As is customary in dynamics of airplanes, the aerodynamic forces acting on the tail surfaces may be neglected except in so far as they enter in the moment equation. This equation need not be considered, however, since it would only furnish information as to how the pilot must adjust the elevator setting in order to keep the enemy bomber in line with his gun. In other words, once the position and velocity vector of the center of gravity of the fighter are known, the orientation of the airplane in space is given by the ballistic constraint that the fighter pilot flies so as to keep the gun bore-axis always pointed at the bomber.

Consequently, all the forces may be assumed to act through the center of gravity of the fighter plane, and it will be seen shortly that the remaining equations of motion determine all the pertinent variables as functions of time. These equations of motion are written for the directions along and normal to the flight path of the center of gravity F of the fighter. The forces and variables to be used are shown in Fig. 1, where T denotes the thrust, L the lift, D the drag, V the true air speed, W the gross weight, φ the angle of glide, α the angle of attack measured with respect to the zero lift direction, and δ the constant angle of wing setting of the fighter plane (δ is thus the angle between the zero lift direction and the thrust line).

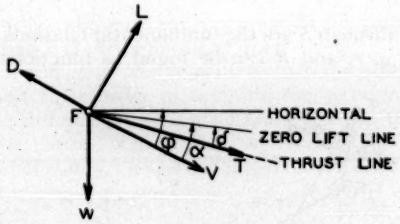


FIG. 1.

The two equations of motion can then be written as follows: in the tangential direction,

$$\frac{W}{g}\frac{dV}{dt} = W \sin \varphi + T \cos (\alpha - \delta) - D, \tag{1}$$

and in the normal direction,

$$\frac{W}{g}\frac{V^2}{R} = L - W \cos \varphi + T \sin (\alpha - \delta), \tag{2}$$

where R is the radius of curvature of the flight path at F. The radius of curvature must satisfy the usual kinematic relation

$$R = \frac{V}{d\varphi/dt}. \tag{3}$$

In addition, two more relations arise from the condition of constraint that the fighter pilot flies so as to keep the gun bore-axis always pointed at the bomber. It is assumed that the axis of the gun bore coincides with the thrust line of the fighter. These equations can be derived quite simply from Fig. 2, where F and B denote the positions of the fighter and bomber, respectively, at time t, and F' and B' the positions at $t + dt$. The speed of the fighter is denoted by V and that of the

bomber by U. If r is the range from bomber to fighter, then $FB = r$ and $F'B' = r + dr$. The vectors $V\,dt$ and $U\,dt$ can be resolved into components along the line FB and perpendicular to it. Terms of second order and higher can be dropped since these will vanish in the subsequent limiting process which yields the desired differential equations. The following equations governing the pursuit conditions are thus obtained:

$$\frac{dr}{dt} = -V\cos(\alpha - \delta) + U\cos(\varphi - \alpha + \delta), \tag{4}$$

$$\frac{d\varphi}{dt} - \frac{d\alpha}{dt} = -\frac{1}{r}[V\sin(\alpha - \delta) + U\sin(\varphi - \alpha + \delta)]. \tag{5}$$

Equations 1 through 5 are the fundamental relations from which the variables V, α, φ, r, and R can be found as functions of time. The

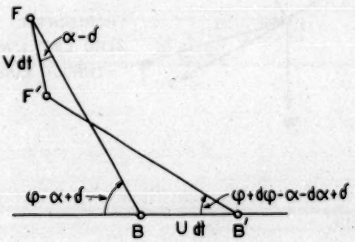


FIG. 2.

radius of curvature R can be eliminated immediately by substituting Eq. 3 into Eq. 2 with the result,

$$-\frac{W}{g}V\frac{d\varphi}{dt} = L - W\cos\varphi + T\sin(\alpha - \delta). \tag{6}$$

The problem is thus reduced to solving a system of four ordinary differential equations provided the forces L, T, and D can be expressed in terms of the other variables.

3. AERODYNAMIC FORCES. REDUCTION OF FUNDAMENTAL EQUATIONS TO DIMENSIONLESS FORM.

The aerodynamic forces L, D, and T are functions of the aerodynamic variables α and V; that is, $L = L(\alpha, V)$, $D = D(\alpha, V)$, and $T = T(V)$. More specifically

$$L = \tfrac{1}{2}\rho V^2 S C_L,$$
$$D = \tfrac{1}{2}\rho V^2 S C_D,$$
$$T = P\eta/V.$$

Here, $C_L = C_L(\alpha)$ is the lift coefficient, $C_D = C_D(\alpha)$ the drag coefficient, S the wing area, P the brake horsepower of the engine, ρ the air density, and η the propeller efficiency. The lift and drag coefficients can in turn be written explicitly as functions (5) of α:

$$C_L = k \sin \alpha, \qquad C_D = A + \frac{C_L^2}{B},$$

where k, A, and B are constant for a given airplane. If b is the wing span, then the aspect ratio is defined as $AR = b^2/S$ and (5, p. 243)

$$k = \frac{2\pi}{(1 + 2/AR)}.$$

In the formula for C_D, the constant A represents the parasite drag of the entire airplane, and C_L^2/B the induced drag.

It has been found more convenient to introduce parameters other than A, B, k, and P, in order to compute the aerodynamic constants appearing in the differential equations directly from the performance data of the fighter plane. This process is described in detail in Appendix I. The new constants, c_1, c_2, c_3, c_4, are defined in the following way:

$$c_1 = \rho k S/2W, \qquad c_2 = \rho A S/2W, \qquad c_3 = \rho k^2 S/2BW, \qquad c_4 = P\eta/W.$$

The aerodynamic forces then take the form

$$L = c_1 V^2 W \sin \alpha, \qquad D = (c_2 + c_3 \sin^2 \alpha) V^2 W, \qquad T = c_4 W/V;$$

and Eqs. 1, 4, 5, 6 become

$$\frac{1}{g}\frac{dV}{dt} = \sin \varphi + \frac{c_4}{V}\cos(\alpha - \delta) - c_2 V^2 - c_3 V^2 \sin^2 \alpha, \tag{7}$$

$$\frac{V}{g}\frac{d\varphi}{dt} = \cos \varphi - c_1 V^2 \sin \alpha - \frac{c_4}{V}\sin(\alpha - \delta), \tag{8}$$

$$\frac{dr}{dt} = -V \cos(\alpha - \delta) + U \cos(\varphi - \alpha + \delta), \tag{9}$$

$$\frac{d\varphi}{dt} - \frac{d\alpha}{dt} = -\frac{1}{r}[V \sin(\alpha - \delta) + U \sin(\varphi - \alpha + \delta)]. \tag{10}$$

The air density ρ changes with altitude. If it is assumed that the change in altitude during the attack does not affect the value of ρ materially, the coefficients c_i may be computed by using the density value corresponding to some average altitude of the range in which the attack takes place.

The equations can be discussed more conveniently if they are put in dimensionless form. To this end, let V_0 be some constant reference speed and set

$$\tau = gt/V_0, \qquad v = V/V_0, \qquad n = U/V_0, \qquad s = gr/V_0^2,$$

where g is, as usual, the acceleration of free fall, $g = 32.16$ ft. sec.$^{-2}$. Using the new coefficients

$$K_1 = c_1 V_0^2, \qquad K_2 = c_2 V_0^2, \qquad K_3 = c_3 V_0^2, \qquad K_4 = c_4 / V_0,$$

Eqs. 7 through 10 can be written as

$$\frac{dv}{d\tau} = \sin \varphi + \frac{K_4}{v} \cos (\alpha - \delta) - K_2 v^2 - K_3 v^2 \sin^2 \alpha, \tag{11}$$

$$\frac{v d\varphi}{d\tau} = \cos \varphi - K_1 v^2 \sin \alpha - \frac{K_4}{v} \sin (\alpha - \delta), \tag{12}$$

$$\frac{ds}{d\tau} = - v \cos (\alpha - \delta) + n \cos (\varphi - \alpha + \delta), \tag{13}$$

$$\frac{d\varphi}{d\tau} - \frac{d\alpha}{d\tau} = - \frac{1}{s} [v \sin (\alpha - \delta) + n \sin (\varphi - \alpha + \delta)]. \tag{14}$$

Examples, to be discussed later, have been based on data for a Republic P-47 fighter flying at an altitude of 10,000 ft. with V_0 taken to be 260 m.p.h., the usual true air speed at which an attack on a bomber is started. For this typical case, the coefficients in the differential equations are $K_1 = 18.93$, $K_2 = 0.0618$, $K_3 = 6.75$, $K_4 = 0.0805$. Results obtained for the dimensionless variable can be interpreted in physical units by noting that $t_{\text{sec}} = 11.85$, $V_{\text{mph}} = 260\ v$, and $r_{\text{ft}} = 4510\ s$. All angles are measured in radians.

4. THEORETICAL INDETERMINACY OF THE PROBLEM.

Once a suitable set of initial conditions is given for the four variables v, s, φ, and α, the mathematical problem of solving Eqs. 11 through 14 with these initial values is well defined. Viewed as a fire-control problem, in which the defending gunner in the bomber will use this information to plan a counter attack, the situation is not quite as simple. It will be seen shortly that the defender can make reasonably good estimates for three of the variables at a given time but is unable to say much about the fourth. This difficulty arises solely from the introduction of aerodynamic considerations into pursuit curve theory. Pure pursuit curves, for example, are constructed under the assumption that both attacker and defender fly at constant speeds. The motion is then governed by two differential equations giving the range and bearing angle. A solution of these equations is completely determined by the initial values of opening range and bearing angle, and these initial values can be estimated by the defending gunner. The same holds true in the case of the lead pursuit curve, but is not so for the problem in question.

In the case of the aerodynamic pursuit curve, the opening range s and bearing angle $\varphi - \alpha + \delta$ can be estimated as before. Further-

more, it has been found from experience that a given type of enemy fighter will begin an attack with a rather well defined speed. Consequently, when the type of attacking aircraft is recognized, the initial speed can be considered as known. The chief difficulty arises, however, in fixing the initial value of the fourth variable, the angle of attack. It is conceivable that any value of α within a certain range can occur at the beginning of the chase, and it would be impossible for the defending gunner to measure this quantity in the air. Thus, it is seen that there is a one parameter family of possible aerodynamic pursuit curves which a given attacker may follow from a given point in space, whereas in the pure pursuit curve a unique curve is obtained.

Various additional assumptions have been proposed to remove this ambiguity, but they can all be shown to lead to difficulties. These additional hypotheses are concerned chiefly with the variation in the speed v during the attack and can be classified as follows: (1) the speed is constant during the attack; or (2) the tangential acceleration, $dv/d\tau$, is zero initially and remains small for the rest of the trajectory; or (3) the throttle setting can be varied in such a way that the speed remains constant. A brief examination will show that in case (1) the system of equations is overdetermined and the additional equation does not reduce to an identity. With a small amount of computation, it can be shown that (2), the assumption that $dv/d\tau = 0$ for $\tau = 0$, leads to initial angles of attack which are much too high in certain practical cases. Finally, hypothesis (3) is not reasonable for overhead attacks since it can be shown that the propeller thrust contributes very little to the tangential acceleration when compared with the effect of gravity. Consequently, a very radical change in throttle setting would be required to make this assumption tenable, at least in the initial phases of the attack.

It seems reasonable then that this difficulty, presented by the lack of information concerning the initial value of the angle of attack, can best be studied by actually integrating the differential equations for various initial values of α and examining the resulting spread in the integral curves. This has been carried out and the results are presented in the next section.

5. INTEGRATION OF THE DIFFERENTIAL EQUATIONS. CONCLUSIONS.

Although Eqs. 11 through 14 cannot be integrated directly in terms of elementary functions, they are of such a form that a simple step-by-step numerical or graphical scheme can be applied. A graphical scheme has been used in this paper since it brings out certain interesting features of the functions involved and does not lead to errors which exceed the limits set by the reliability of the estimates of the initial values of the variables made by the defending gunner. The method becomes quite apparent if Eq. 12 is divided through by v. Then the resulting system

of equations will contain only the derivatives $dv/d\tau$, $d\varphi/d\tau$, $ds/d\tau$, $d(\varphi - \alpha)/d\tau$ on the left hand side; and each derivative will appear in just one equation. The integral curves are approximated by using a finite number of values of the independent variable τ, say $\tau_1, \tau_2, \cdots, \tau_n$, where the interval, $\tau_{k+1} - \tau_k$, between two consecutive steps is suitably small. If the values of the functions v, s, φ, $\varphi - \alpha$ (and hence α) are known at τ_k; then the derivatives of these functions can be found at τ_k by evaluating the right hand side of Eqs. 11 through 14. The functional values at τ_{k+1} can then be determined by approximating the integral curves by straight line segments with slopes equal to the derivatives at τ_k. It has been found that intervals in τ of length 0.05 are quite suitable, although these may be changed at will during the process of graphical integration. The derivatives are not evaluated by computation but rather through nomograms which then reduce the entire integration process to graphical procedure. A detailed discussion of the construction of one such nomogram is given in Appendix II.

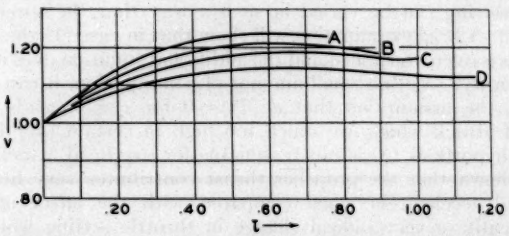


FIG. 3.

Figures 3 through 8 contain the results of the integration for four different sets of initial conditions. Pure pursuit curves with corresponding initial conditions have also been included. The initial conditions used for the *aerodynamic pursuit curves* are $v = 1.0$, $s = 0.40$, $n = 0.77$, $\delta = 0.035$, and (A) $\varphi - \alpha = 1.012$, (B) $\varphi - \alpha = 0.838$, (C) $\varphi - \alpha = 0.663$, (D) $\varphi - \alpha = 0.489$, where the angles are all measured in radians. It will be seen shortly that the angle of glide, φ, has a "natural" initial condition determined by the initial values of the other three functions. The integration has been continued up to collision ($s = 0$). The initial conditions for the pure pursuit curves are $s = 0.40$, (a) $\varphi - \alpha + \delta = 1.047$, (b) $\varphi - \alpha + \delta = 0.873$, (c) $\varphi - \alpha + \delta = 0.698$, (d) $\varphi - \alpha + \delta = 0.524$. These conditions correspond to initial bearing angles of 60°, 50°, 40°, 30°, respectively.

Figure 3 shows the variation in the relative velocity v as a function of τ for the four initial bearing angles. As might be expected, v increases more rapidly for a higher bearing angle since the effect of the accelera-

tion of free fall is more pronounced. Specifically, it is seen that v increases rather rapidly to a maximum value and tapers off slowly until collision. In curves (C) and (D), it should be noted that the rate of decrease diminishes toward the end of the run. The maximum value of v in case (A) is 24 per cent higher than the original value. In other terms, the true air speed increases from 260 m.p.h. to about 322 m.p.h. In case (D), v increases by 11.5 per cent of its original value, that is, from a true air speed of 260 m.p.h. to one of about 298 m.p.h. Thus there seems to be little chance that v remains almost constant except in a pure tail chase.

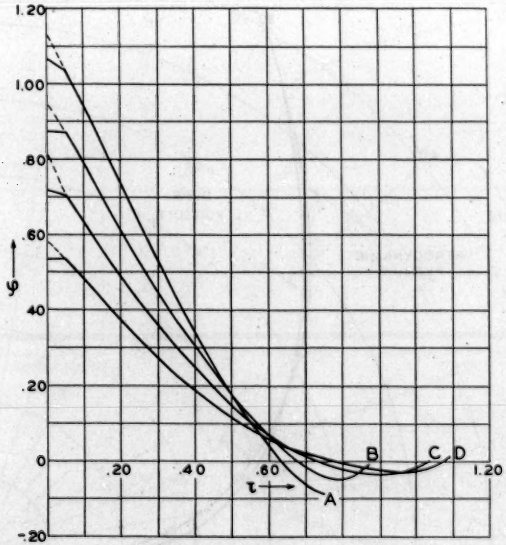


FIG. 4.

The results shown in Fig. 4, φ *versus* τ graphs, do much to settle practically the question of the theoretical indeterminacy of the problem discussed in Section 4. Since v, s, and $\varphi - \alpha$ are given initially, φ can be found once the initial value of α has been decided upon. Several initial values of α have been tried in the range $2° \leqq \alpha \leqq 12°$, with the same initial values for v, s, and $\varphi - \alpha$. The corresponding integral curves were found to have a very interesting and fortunate property. Unless a particular initial value of α, which will be called the "natural" initial value of α, has been chosen, the resulting φ *versus* τ curve has a very sharp hook in the interval $0 \leqq \tau \leqq 0.10$. This natural initial

value depends on the initial values of the other variables. The hook has been found to occur when α is initially either smaller or larger than the natural value. The values of φ at $\tau = 0.05$ were found to be the same, regardless of which initial values of α were taken.[3] Starting from the given initial value of φ, the differential equation can be integrated for three or four steps and a new initial value of φ found by extrapolating backwards along the line joining φ (0.05) and φ (0.10). This new value

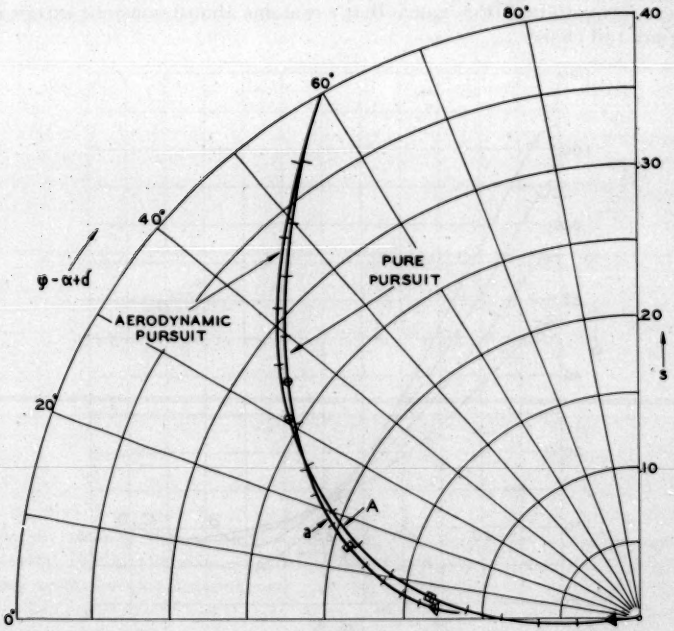


FIG. 5.

of φ, as well as the previous initial value of v, s, and $\varphi - \alpha$ can be taken as a new set of initial conditions from which the integration can be started anew.

In Fig. 4, the integration from the extrapolated $\varphi(0)$ is shown by a dotted line. The solid line represents the original integration. By carrying out this process, it has been found that $\varphi(0.05)$ is the same

[3] This behavior is reminiscent of the "boundary layer effect" found in certain types of differential equations, although this usually occurs in boundary value problems rather than in initial value problems of the type under discussion.

for either initial value of φ and the curves from $\tau = 0.05$ on are identical. In addition, the change in the initial value of φ has no effect on the integral curves of the other three functions. This fact was checked quite carefully by using much finer division in τ than those used for the rest of the integration. Other examples, not included here, have been worked out just far enough to verify this result. Consequently, it may be concluded that the system of equations, Eqs. 11

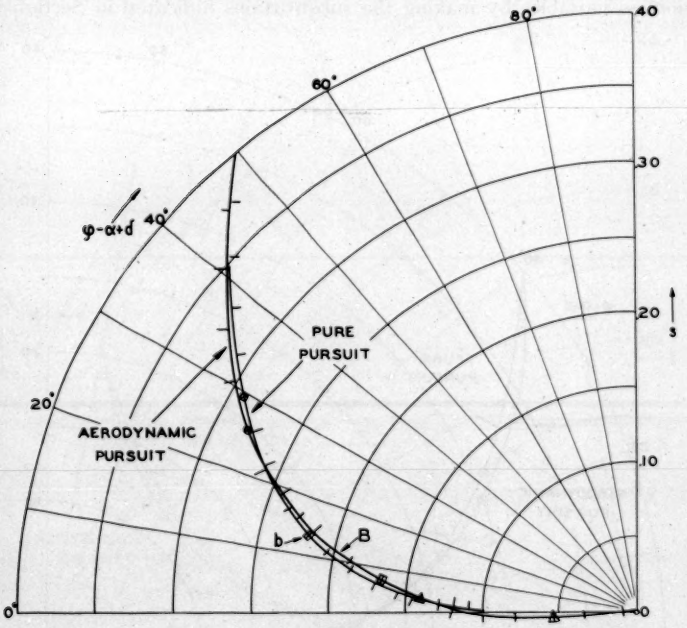


FIG. 6.

through 14, has a "natural" initial value for φ once those for v, s, and $\varphi - \alpha$ are given; that is, after a small interval in τ, the integral curves appear to be the same for the extrapolated value of $\varphi(0)$ as for any other $\varphi(0)$ within the range $2° \leqq \alpha \leqq 12°$.

Figures 5 through 8 show the comparison between the aerodynamic pursuit curve and the pure pursuit curve by means of so-called "bomber coordinates." These will be considered shortly in detail. First, it should be pointed out that the standard equations for the pure pursuit

curve in range and bearing angle coordinates are given by

$$\frac{d(\varphi - \alpha + \delta)}{dt} = -\frac{U \sin(\varphi - \alpha + \delta)}{r}, \tag{15}$$

$$\frac{dr}{dt} = -V + U\cos(\varphi - \alpha + \delta). \tag{16}$$

These can be changed quite readily into differential equations in dimensionless variables by making the substitutions indicated in Section 3.

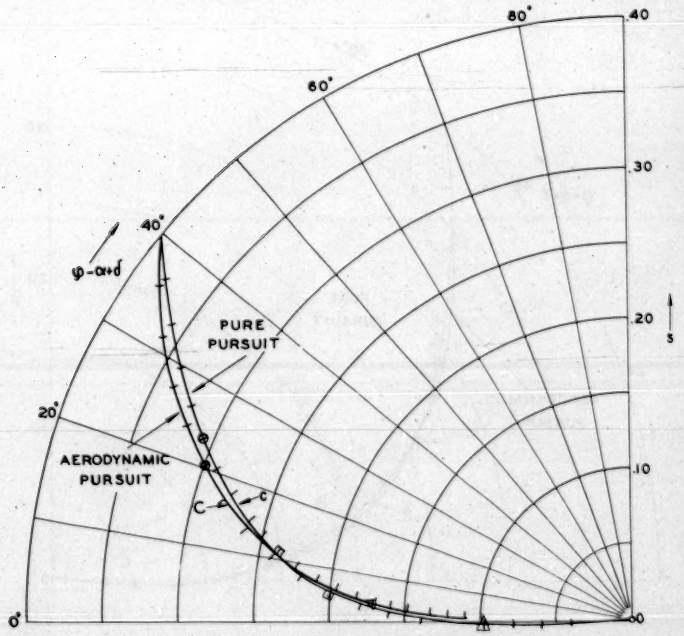


FIG. 7.

It should be noted that V is constant in the case of the pure pursuit curve. Equations 15 and 16 take on the following dimensionless form

$$\frac{d(\varphi - \alpha + \delta)}{d\tau} = -\frac{n \sin(\varphi - \alpha + \delta)}{s}, \tag{17}$$

$$\frac{ds}{d\tau} = -1 + n\cos(\varphi - \alpha + \delta). \tag{18}$$

This pair of equations can be integrated graphically by a method which is quite similar to that used for the differential equations of the aerodynamic pursuit curve. The computations have been carried out for the initial conditions indicated at the beginning of this section.

The results, obtained from the integration of the aerodynamic pursuit equations and the pure pursuit equations, for the variables $s = s(\tau)$ and $\varphi - \alpha + \delta = \varphi(\tau) - \alpha(\tau) + \delta$ have been plotted in bomber coordinates, that is polar coordinates with $\varphi - \alpha + \delta$ as the

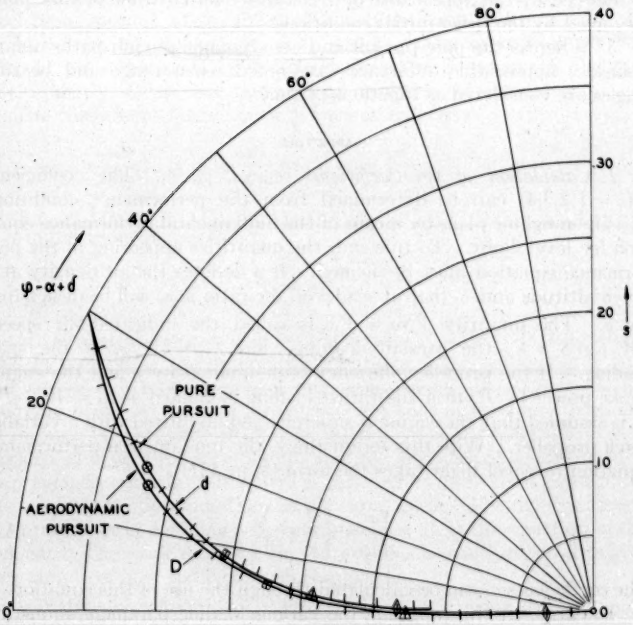


FIG. 8.

angle and s as the radial distance. In addition, positions corresponding to increments in τ of 0.05 have been marked. It is seen that when the two paths are considered as geometrical curves in the $(s, \varphi - \alpha + \delta)$-plane, they are almost identical. On the other hand, if they are studied as trajectories, that is, if the time is considered at which a certain position along these practically coincident paths is reached, the two motions are seen to differ appreciably. From the point of view of fire-control,

then, there is a considerable difference in the target path depending on whether aerodynamic effects are considered or not.

Summarizing the major qualitative results obtained by integrating the differential equations of the aerodynamic pursuit curves and the pure pursuit curves, it has been seen that

1. The changes in air speed occurring along an aerodynamic pursuit curve are of considerable magnitude.
2. The difficulty of assigning the initial value of the angle of attack is resolved by the appearance of a "natural" initial value of this quantity fixed by the other initial conditions.
3. Whereas the pure pursuit and aerodynamic pursuit paths almost coincide, appreciable differences are noted when range and bearing angles are considered as functions of time.

APPENDIX.

I. Calculation of the Coefficients, c_1, c_2, c_3, c_4. The coefficients $c_i (i = 1,2,3,4)$ can be determined from the performance conditions of a given fighter plane by means of the fundamental performance equation for level flight. To this end, the quantities appearing in the performance equation must be defined. If ρ denotes the air density at a given altitude and ρ_0 that at sea level, the ratio ρ/ρ_0 will be designated by σ. The quantity $V\sqrt{\sigma} = V_i$, is called the indicated air speed, $2W/\rho_0 AS = \lambda_p$ the parasite loading, and $\lambda_s = 2W/\rho_0 BS$ the span loading. If the propeller efficiency is designated by η and the engine brake power by P, then the thrust loading is defined as $\lambda_t = W/(\eta P)$. It is assumed that the engine is supercharged and fitted with a variable pitch propeller. With this terminology, the fundamental performance equation for level flight takes the form (5, p. 431)

$$\frac{\sqrt{\sigma}}{\lambda_t} = \frac{V_i^3}{\lambda_p} + \frac{\lambda_s}{V_i}. \tag{A1}$$

The coefficients c_i can be calculated through the use of this equation.

To carry out this program, the various loading parameters must be computed for the level flight speed and altitude at which the attacks are flown. It should be noted that λ_t is the only loading parameter which depends upon the throttle setting; λ_s and λ_p are essentially functions of the geometry and weight of the airplane. Let us assume that the standard information about the performance of an airplane ordinarily supplied with its description is known; that is, the propeller efficiency, the maximum engine brake power P, the corresponding maximum level flight speed $\bar{V}$ for a certain altitude (or density ratio $\bar{\sigma}$) are given in addition to the geometry of the airplane and the gross

weight. Then

$$\bar{\lambda}_t = W/\eta \bar{P},$$

$$\lambda_s = \frac{2W}{\rho_0 BS} = \frac{2W}{\rho_0 \pi ARS} = \frac{2W}{\rho_0 \pi b^2},$$

and

$$\bar{V}_i = \bar{V}\sqrt{\sigma}.$$

Now λ_p can be computed from Eq. A1. Let λ_t be the thrust loading corresponding to the engine brake power which will yield the required level flight speed V at the given altitude (or density ratio σ). As can be seen from the definitions of λ_s and λ_p, these quantities are not affected by a change in engine brake power or a change in altitude. Consequently, λ_t can then be found by using Eq. A1 again.

The coefficients c_i have been defined as follows:

$$c_1 = \frac{\rho k s}{2W}, \qquad c_2 = \frac{\rho A S}{2W}, \qquad c_3 = \frac{\rho k^2 S}{2BW}, \qquad c_4 = \frac{P\eta}{W}.$$

Then $c_4 = 1/\lambda_t$, $c_2 = \sigma/\lambda_p$, and c_1 can be computed directly. Finally, c_3 is found from the relation

$$c_3 = c_1^2 \frac{\lambda_s}{\sigma}.$$

II. Graphical Integration of the Differential Equations. The method used in integrating the differential equations of the aerodynamic pursuit curves is a modification of one proposed by W. Richter (6) for studying power-off flight of airplanes. For each of the four equations, 11 through 14, a separate work sheet is used. The left hand side of each work sheet is used for a graph of one of the variables as a function of τ. As previously remarked, this curve is obtained by using short segments of the tangents as approximations to the curve itself. The right hand side of the work sheet contains a nomogram which gives the direction of the tangent. The work sheet for Eq. 13 will be discussed in detail to give an example of how the technique is applied.

Equation 13 has been given previously as

$$\frac{ds}{d\tau} = -v\cos(\alpha - \delta) + n\cos(\varphi - \alpha + \delta).$$

The ratio n of the speeds of bomber and fighter is taken as $n = 0.77$. Consider now two points (x, y) and (x', y'). If $y = n\cos(\varphi - \alpha + \delta)$, $x = 0$, $y' = v\cos(\alpha - \delta)$, $x' = -1$, the line joining (x, y) and (x', y') will have the slope required by Eq. 13. The nomogram itself can be constructed in the following manner. A simple scale for $n\cos(\varphi - \alpha + \delta)$ is marked off and labelled in terms of $\varphi - \alpha$. The left hand section of the nomogram is a net of curves. The abscissas start from a point one

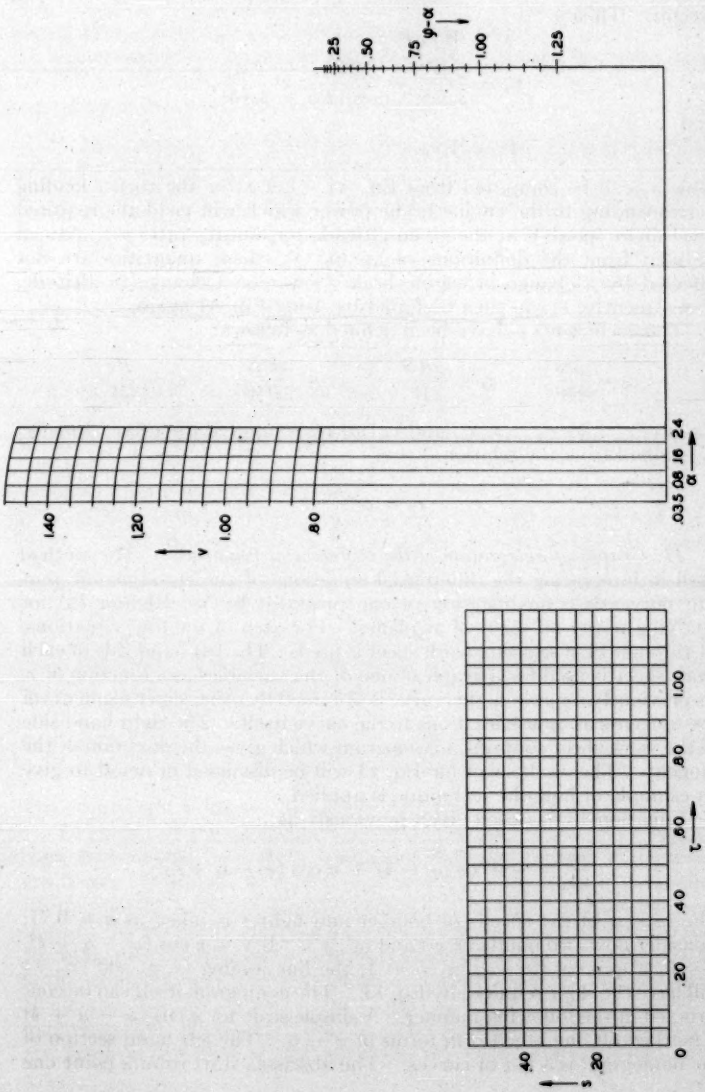

φ-α
.25
.50
.75
1.00
1.25
α
.035
.08
.16
.24
v
1.40
1.20
1.00
.80
τ
0
.20
.40
.60
.80
1.00
s
.40
.20

FIG. 9.

unit to the left of the $n \cos(\varphi - \alpha + \delta)$-scale; they are laid off according to $\alpha - \delta$ and labelled in terms of α. The ordinates have the value $v \cos(\alpha - \delta)$, and the net itself is composed of the curves $v = \text{const.}$ and the lines $\alpha = \text{const.}$ To use the nomogram, one locates the proper point in the (α, v)-net, projects it onto the vertical line $\alpha = 0.035$ (that is, $\alpha = \delta$), and joins this projection to the proper point on the scale for $\varphi - \alpha$. This will give the desired slope which is parallel to the tangent to the integral curve. The work sheet is shown in Fig. 9.

When the work sheets are completed for each of the four differential equations, they are used in the following manner. Given the initial values of the four variables, parallels to the initial slopes can be found from each of the nomograms, and the first linear approximations laid out. These will yield a set of values for the variables corresponding to the next value of τ and the whole process can be repeated. The length of the intervals in τ can be changed at will and can be refined for any one of the equations if necessary.

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(2) M. M. DAY AND W. PRAGER, "The Aerodynamic Pursuit Curve," Applied Mathematics Panel Memo 106.1 M.
(3) L. W. COHEN, "Equations for Aerodynamic Lead Pursuit Curves," Applied Mathematics Panel Report 153.1 R.
(4) G. H. HANDELMAN AND W. R. HELLER, "Aerodynamic Lead Pursuit Curves for Overhead Attacks," Applied Mathematics Panel Report 106.2 R.
(5) RICHARD VON MISES, "Theory of Flight," McGraw-Hill Book Company, Inc., New York and London, 1945, pp. 140–141.
(6) W. RICHTER, *Ingenieur Archiv.*, Vol. 10, p. 292 (1939).

The Mutron Universal Analyser (*Instrument Practice*, Vol. 3, No. 1).—Mutron, Ltd., of Castle St., Edinburgh, manufacturers of the Mutron universal analyser, recently exhibited several industrial applications of electronic principles at the Engineering Centre, Sauchiehall St., Glasgow.

The apparatus consists essentially of a wave generator and amplifier suitably adapted to enable it, among other things, to trace faults in cables, to locate sources of excessive vibration in machinery, and to check telephone equipment. Its use in tracing faulty cables makes it extremely valuable to the National Coal Board and the equipment is also adaptable for service with mine rescue teams in picking up messages from men trapped behind large roof falls.

The apparatus is also of use on board ships, mainly for locating cable faults, and has been used in some cases to determine the thickness of walls in civil engineering works.

Atomic "Tracer" is Research Tool.—Use of radioactive isotope tracers as a new research tool is enabling plant scientists to learn new facts of the processes by which plants grow, says the U. S. Department of Agriculture. Radioactive elements give off a radiation as they disintegrate. This radioactivity makes it possible to detect or trace a radioactive element wherever it may go in the soil and through plants, says the Bureau of Plant Industry, Soils, and Agricultural Engineering.

Research with radioactive tracers is not limited to fertilizers. The new tool lends itself to a wide variety of uses. Scientists are already using it to learn how the many growth regulating chemicals modify plant growth. By "tagging" a compound with radioisotopes they are able to follow it throughout the plant as it is absorbed and moves about.

In the fertilizer field, experiments with radio-phosphorus have revealed that crops vary in their use of fertilizer phosphorus. In field experiments, corn derived a large part of its phosphorus from fertilizer during the early stages of growth, but when the crop was near maturity fertilizer furnished only a small part of the phosphorus. In contrast, potatoes on the same soil leaned heavily on the fertilizer at all stages. Cotton and tobacco used more phosphorus from fertilizer during early growth than when they approached maturity, but the percentage differences between the two stages were not nearly so striking as with corn. The significance of these differences is not yet clear, but it appears that radio-tracer research is pointing the way to more efficient use of fertilizers on farms.

Tracer experiments in the greenhouse indicate that phosphate from green manure is almost as efficient as superphosphate. This will call for field tests.

It is possible to use radioactive sulphur, calcium, manganese, zinc, iron and chlorine in the same way that radio-phosphorus is being used as a scientific tool. Scientists are now learning how to use this tool as an aid to answering their own questions.

FEED-BACK IN MAGNETIC AMPLIFIERS.

BY

ALAN S. FITZGERALD.[1]

Part I.

GENERAL.

Feed-Back Arrangements.

The use of regeneration or feed-back in magnetic amplifiers gives rise to some extremely interesting and intriguing phenomena which can be applied in a number of different ways in the design and use of this apparatus.

There are several different methods of bringing about the feed-back effect by both direct and indirect means. For example, an additional d-c. saturating winding may be connected in series with the rectified

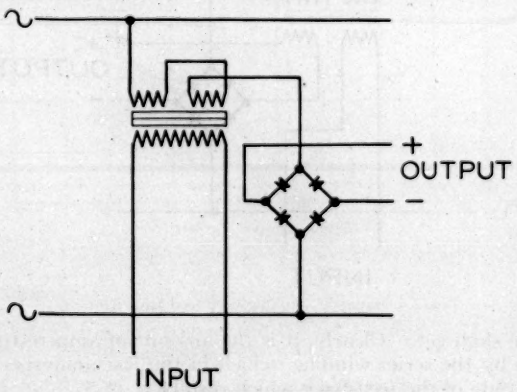

FIG. 1. Neutral type magnetic amplifier.

output of the amplifier (1),[2] or a resistor carrying the output current may be included in the input circuit (2). There are various other arrangements by means of which the direct current magneto-motive force applied to the core of the saturating reactor may be augmented in accordance with the amount of the magnetic amplifier output.

The simple series winding is the least complicated arrangement to illustrate, and to describe and explain. Accordingly, this method will

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

be adhered to in the present paper. Other equivalent or analogous arrangements may, of course, be employed when these alternative methods may be convenient or advantageous.

A single magnetic amplifier element or stage is shown in Fig. 1. Such an arrangement is of the neutral type; that is to say, its response is independent of the polarity of the input current. The addition of the series or feed-back winding is illustrated in Fig. 2.

Several qualitatively different types of action result, in accordance with the quantitative extent to which the feed-back effect is introduced.

The amount of feed-back will obviously depend upon the number of turns of the series winding. But this is not the only significant element involved. The resistance of the output circuit is equally pertinent. The higher the value of the output circuit resistance the less output

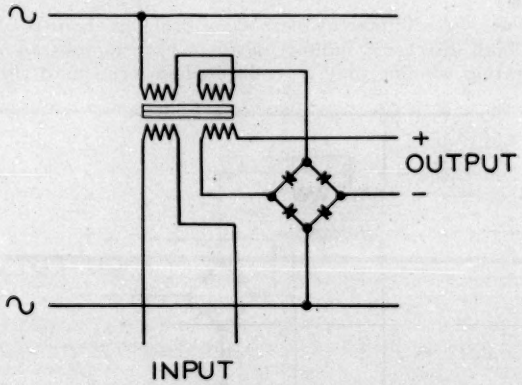

FIG. 2. Magnetic amplifier with feed-back winding.

current we shall get. Clearly, it is the amount of ampere-turns which are set up by the series winding, which in the last analysis determines the magnitude of the feed-back which results.

In this connection we must not overlook the fact that the rectifier comprises a portion of the output circuit resistance. Furthermore, the efficiency of rectification is an element in the amount of the feed-back effect. Thus, in a magnetic amplifier, changing one rectifier for another will sometimes cause an increase or a decrease in the feed-back. Also the fact that the rectifier characteristics are non-linear introduces a complication in the prediction of the results of the use of any given feed-back structure.

If we plot a curve showing the relation between the input and output currents for the circuit of Fig. 1, showing both positive and negative input values, we obtain a result such as is shown in Fig. 3. The curve

is seen to be symmetrical about the zero axis; that is to say, the amplifier is of the neutral type.

If similar curves be obtained for the series feed-back arrangement of Fig. 2, it will be found that, in accordance with the amount of feed-back employed, the resulting action will exhibit three separate and distinct phases, or characteristic types of response. These may be described, respectively, as:

(*a*) Unitary or singular stability,
(*b*) Binary or plural stability, and
(*c*) Absence of stability—resulting in a floating condition.

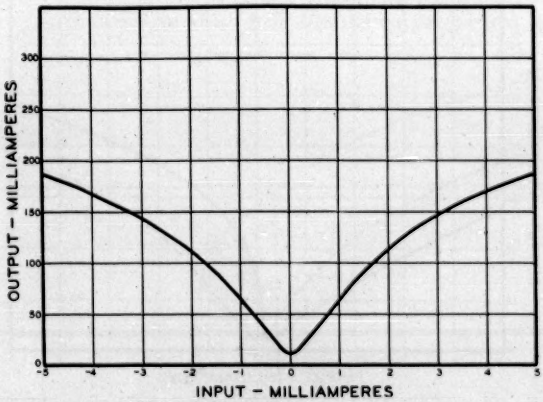

FIG. 3. Response characteristic of neutral amplifier.

Singular Stability.

Figure 4 shows a curve of the same type as that of Fig. 3, when the circuit has the following characteristics:

1. The number of turns of the series or feed-back winding is not more than one half of the total number of turns in series of the a-c. winding. For example, in Fig. 4 the total a-c. turns are 430 and the series turns, 200.

2. The total resistance of the output circuit, exclusive of the rectifier, is such that, in the absence of any feed-back, that is to say, if the circuit is as in Fig. 1, the current flowing therein is reduced to approximately 75 per cent of the value which occurs when there is no additional circuit resistance.

The total circuit resistance is maintained at this constant value in all of the curves of Figs. 3 to 12, inclusive.

While the phenomena to which this paper has reference have no more relevance to communication technology than to any other field of study, it is possible that the text may be somewhat more concise if we may refer to the application of input current, power, or excitation, by the conventional expression "*signal.*" When the input excitation is additive, in relation to the feed-back winding ampere-turns, we shall refer to the signal as being of positive polarity. When the input opposes the series winding, it will be designated as a negative signal.

In Fig. 4 it is immediately evident that the circuit of Fig. 2 responds in a different manner to a negative signal than is the case when the

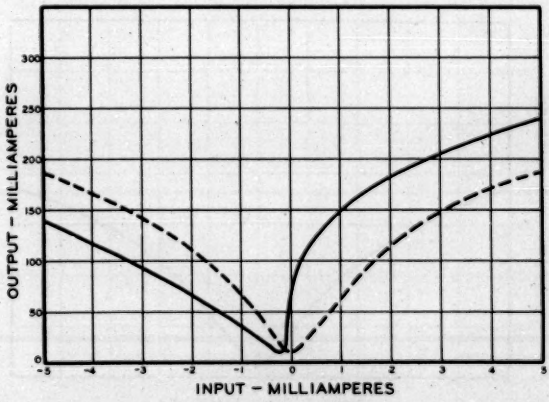

FIG. 4. Response characteristic of feed-back amplifier. Series winding 200 turns.

polarity of the signal is positive. The curve of Fig. 4, unlike that of Fig. 3, is not symmetrical about the zero axis. With a positive signal, the effect of the feed-back is to increase the current to a value greater than that obtained with the Fig. 1 circuit. When the signal is negative the current is decreased. To bring out more clearly the extent of this difference, the neutral type curve of Fig. 3 is repeated again in broken lines in Fig. 4.

For any number of series turns less than 200, the figure to which Fig. 4 relates, other curves may be plotted and all of these curves would lie between the full-line and broken-line curves shown in Fig. 4.

For all such values of series turns the condition of singular stability will obtain. That is to say, if a signal of either positive or negative polarity be applied, a resulting change will take place in the output current, as long as the signal is maintained; but when the signal is withdrawn, the output current will revert to exactly the value previously existing.

Binary Stability.

If the number of series turns be increased to a figure approximately double the previous value, so that the feed-back turns are of the same order of magnitude as the total number of the a-c. turns in series, we obtain the very interesting result shown in Fig. 5. This is a curve of the same general type as in Fig. 4 when the series winding consists of 450 turns.

The significance of this curve illustrating binary stability can perhaps be explained most simply if we may follow the action of this circuit through a cycle of operation. Suppose, for example, that initially the circuit receive a negative signal of 5 milliamps. If we observe the reading of an instrument which indicates the output current we shall

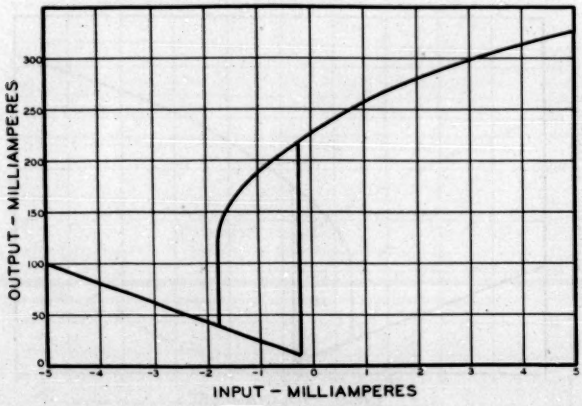

FIG. 5. Response characteristic of feed-back amplifier. Series winding 450 turns.

note that its pointer will be stationary at a reading of 100 milliamps. Conditions will be entirely stable.

Suppose, now, we slowly reduce the value of the negative signal. We shall observe that the output current will likewise be commensurately decreased. For example, at a signal of -3 ma. we shall note an output current of approximately 60 ma. The circuit continues to remain in a condition of stability.

However, if we further, slowly, reduce the signal, at a value of about -0.25 ma. input, a sudden discontinuity phenomenon will manifest itself. The pointer of the output current milliammeter will suddenly jump from a value of 10 ma. to a value of nearly 220 ma. At this value a second range of stability now obtains. If the signal be further adjusted in the same direction, that is to say, in the positive sense, the output current will increase as the positive signal is increased

and the condition will be one of stability; if the signal be withdrawn and re-established the same value of output current will ensue, in accordance with Fig. 5. Thus, for example, if the signal be +3 ma. the output milliammeter will indicate 300 ma.

Now suppose we adjust the signal in the opposite sense—towards negative values. The output current will, in accordance with the curve, decrease as the signal is reduced. When the signal is reduced to zero the output current will be 225 ma.; but when the signal reaches the value of −0.25 ma., the action obtained with increasing signal values will not be repeated in reverse. The second, or upper, range of stability will be maintained for negative signal levels beyond the value of −0.25 ma. The circuit will not transfer to the lower range of stability until a signal of −1.8 ma. is reached. At this value a similar discontinuity

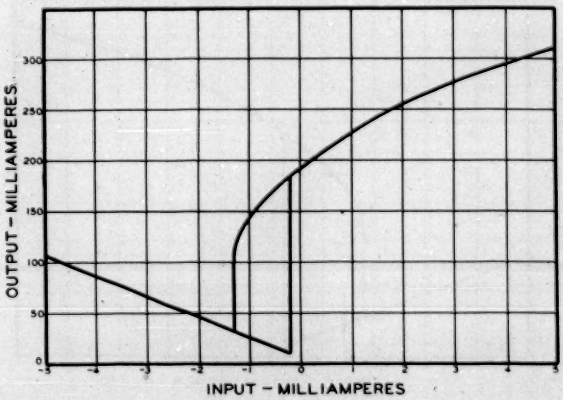

FIG. 6. Response characteristic of feed-back amplifier. Series winding 400 turns.

condition occurs and the lower range of stability is resumed. It is to be noted, however, that the transfer to the lower range is less abrupt than that which takes place at −0.25 ma. signal when the signal is adjusted in the positive direction. In this latter case the action is very sharply defined and there is no indication, when watching the pointer of the output meter, of the approach to the critical point. When adjusting the signal in the negative direction, however, as is indicated by the shape of the curve, the point of discontinuity is approached more gradually, and the impending sudden switch from the upper to the lower stability ranges is pre-indicated by the action of the instrument pointer. Thus, when the signal reaches the value of −1.8 ma., the output current falls from a value in the neighborhood of 130 ma. to 40 ma., corresponding with the lower portion of the curve originally traversed when the signal was adjusted from −5 ma. in the positive direction. If the signal

now be restored to the latter value, that is to say, −5 ma., the output current, as before, will again be 100 ma. The circuit will be in a condition of complete stability, in the lower of the two ranges.

Figure 6 shows a similar curve for 400 series turns, and Fig. 7 shows the action obtained when the series turns are 350.

It is of special interest to note in Figs. 5, 6, and 7, that the ratio of the change in input current necessary to bring about transfer from one range of stability to the other, to the resulting change in output current, which is a quantity related to the gain, is increased by reducing the amount of feed-back.

Floating Action.

By selecting a number of turns for the series winding somewhere in

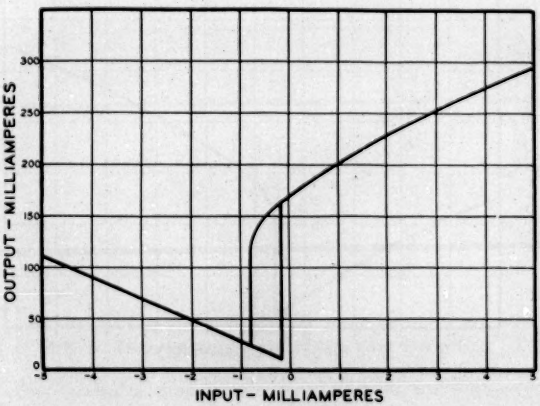

FIG. 7. Response characteristic of feed-back amplifier. Series winding 350 turns.

the range of from 60 to 75 per cent of the a-c. turns, a completely different characteristic or action pattern results. This is illustrated in Fig. 8 in which the number of series turns is 300.

As is foreshadowed by the results indicated in Figs. 5, 6, and 7, the loop is now completely closed and the relation between the input and the output currents is now exactly the same whether the input be varied from positive to negative or in the opposite sense.

It is evident from Fig. 8 that when the input is around −0.4 ma., at which value the curve has a section which is vertical, an extremely small positive or negative increment in the signal will result in a substantial change in the value of the output current. In other words, the circuit under these conditions is capable of manifesting an exceptionally high gain.

This special condition is accompanied by a most interesting phenomenon which may be most usefully applied in the development of magnetic amplifiers. When the circuit constants are adjusted to exactly the proper values, the output current, with a signal of fixed and finite magnitude, is of indefinite and indeterminate value between the limits of 10 and 110 ma. Under these conditions the pointer of the output milliammeter manifests an apparent behavior almost identical with that of an instrument of the uncontrolled type such as a flux-meter. That is to say, in the absence of any constraining signal effect tending to increase or decrease the output current, it tends to remain for quite a prolonged period at any value between the above limits at which it may have been positioned.

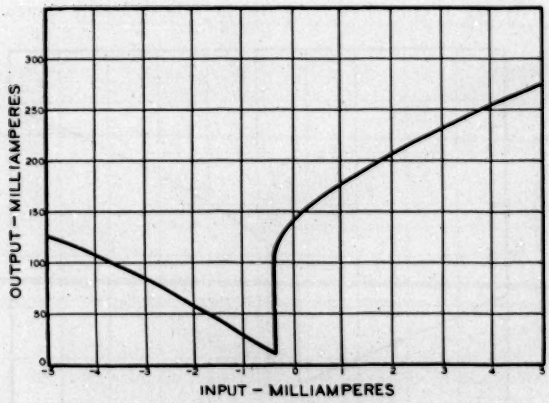

FIG. 8. Response characteristic of feed-back amplifier. Series winding 300 turns.

When this condition exists, the output current is capable of being controlled or modulated, by some external or separate agency which can furnish an appropriate signal, to any value between the maximum and minimum values embraced by the vertical section of the curve in Fig. 8.

This characteristic is one of the most important and valuable features of the use of feed-back in magnetic amplifiers and the manner in which it may be applied will be described in greater detail below.

Effect of Bias Winding.

It will be noted on referring to all of the foregoing curves with the exception of Fig. 3, that the most interesting relation between the input current and the output current obtains at a signal level other than zero. For example, in Fig. 4, with a zero signal the output current is 70 ma.,

whereas in Fig. 3 in which there is no feed-back, the current with a zero signal is 10 ma. This, of course, is due to the fact that the I_0, or residual magnetizing current, which has a value of 10 ma. as seen in Fig. 3, flows in the series winding, thereby increasing this value by cumulative action from 10 to 70 ma.

This increased value of I_0 is undesirable because, if the output of the circuit is to be applied to a second stage it will be necessary to annul or compensate for this higher value instead of 10 ma. and this is likely to result, in one way or another, in a reduction in the gain of this second stage. For example, if the second stage comprises a compensating winding of the type described by the author in a previous paper (3), such a winding would require more ampere-turns if it be necessary to compensate for 70 ma. than for 10 ma., as a result of which the compensating winding would occupy a larger portion of the window area

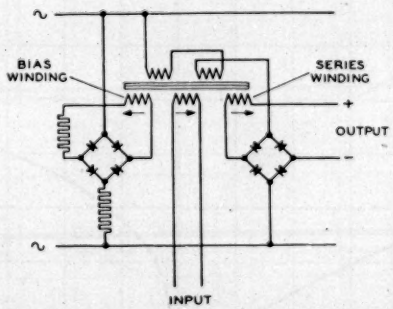

FIG. 9. Magnetic amplifier with feed-back and bias windings.

of the core punching thus leaving less available for the second stage input winding, which would result in reduced gain.

Furthermore, since the slope of the curve, in Fig. 4, decreases with increase in the positive signal, the higher the value of the residual current the less will be the sensitivity; that is to say, the amount of the change in the value of the output current that results from a given signal increment. For example, in Fig. 4, it is seen that if we increase the signal from zero to +0.2 ma. we cause the output to increase from 70 to 100 ma., a net current gain of 30 ma. But if, instead of changing the signal from zero to +0.2 ma. we change it from −0.2 ma. to zero we obtain a resulting output current change of from 10 to 70 ma., which gives us a difference of 60 ma.

Accordingly, whenever a series feed-back winding is employed it is desirable to provide also an additional bias winding, referred to in a previous paper (4) and carrying a current of appropriate and constant

value. This winding opposes the excitation of the series winding due to the I_0 or normal residual current.

Figure 9 shows a single magnetic amplifier element with both a feed-back and a bias winding. The latter is supplied from the a-c. source through an additional rectifier and resistors of the proper value for furnishing the amount of excitation required.

By adjusting the value of the bias current it is possible to reduce the value of the output current, when the input signal is zero, to the same value as in Fig. 3, which is 10 ma. That is to say, the curve shown in Fig. 4, which reaches its minimum value with an input of −0.2 ma., may be displaced laterally so that the minimum comes at zero input as shown in Fig. 10. A signal of +0.2 ma. will now raise the output current from 10 to 70 ma., an increase of 60 ma.

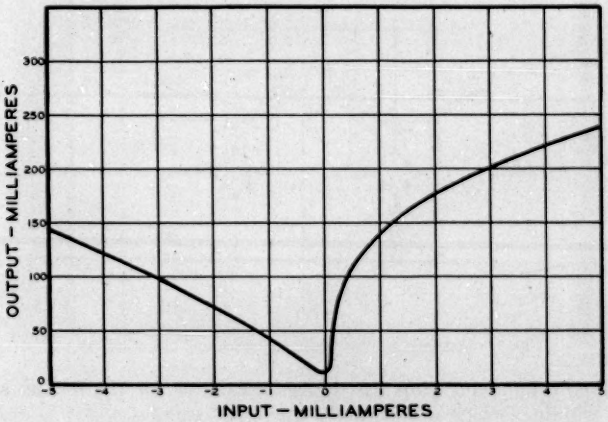

FIG. 10. Response characteristic of amplifier with feed-back and bias windings. Series winding 200 turns.

However it is not necessarily always desirable to use a bias current that gives minimum I_0 at zero input. It is found in practice that a slightly lower value of bias current is usually to be preferred such that the output current at zero input may be slightly greater than the minimum value. Clearly, the optimum value of the bias current will be that at which the slope of the curve is a maximum where it intersects the input zero axis, since this will give the maximum change in output current with an input signal of low value. For example, in Fig. 10, if the bias current be adjusted so that the minimum value of 10 ma. occurs at −0.1 ma., the output current at zero will be 20 ma. and a

signal of +0.2 ma. will increase the output current from 20 to 90 ma., giving an increment of 70 ma.

It will be observed that in Fig. 9, for the purpose of determining and adjusting the bias current to the proper value, two resistors are shown, one included in the rectifier a-c. connections, and one connected in the rectifier output circuit.

The reason for this is as follows.

In a previous paper (5) the author has referred to the phenomena which result when a rectifier is located in a circuit in which there may exist a double-frequency transformer voltage picked up in one saturating reactor d-c. winding due to the presence, in another d-c. winding, of saturating current containing a ripple component due to the fact that this current is supplied from another rectifier.

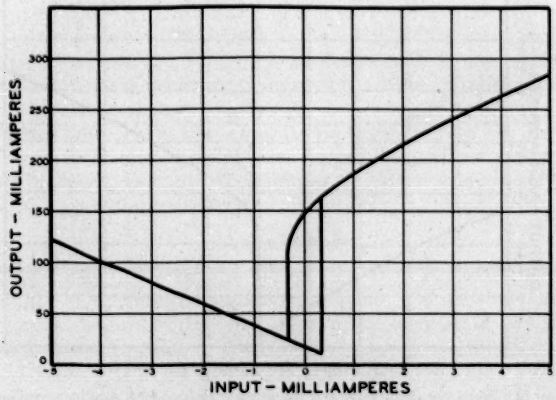

FIG. 11. Response characteristic of amplifier with feed-back and bias windings. Series winding 350 turns.

Because of the series or feed-back winding in Fig. 9, which is supplied by a full-wave rectifier, a double frequency transformer e.m.f. is set up in the bias winding. This causes some rectified current to flow in the bias winding due to half-wave action of the bias rectifier, even though the a-c. leads to the bias rectifier be opened.

For the purpose of adjusting the proper value of the current supplied to the bias winding from the a-c. source through the normal full-wave action of the rectifier, only one resistor is actually necessary and this might be placed in either the a-c. or the rectifier circuit. However, if the resistor is placed on the a-c. side of the rectifier it is not included in the local circuit which is involved when half-wave rectified current is set up in the bias winding due to the feed-back winding ripple or

double frequency transformer voltage. On the other hand, if the bias current adjusting resistor is put in the output circuit of the rectifier it substantially cuts down this "sneak" current to a value which is in most cases negligible. Since it is, in general, preferable to have some resistance in the a-c. leads to the rectifier instead of connecting the latter directly to the a-c. source, the total resistance necessary to furnish the desired current may be divided between the a-c. and d-c. circuits, if desired, as shown in Fig. 9.

It is to be noted that the amount of bias current required is roughly proportional to the amount of feed-back. That is to say, increasing the number of series turns, or decreasing the output circuit resistance, will call for an increase in the bias current.

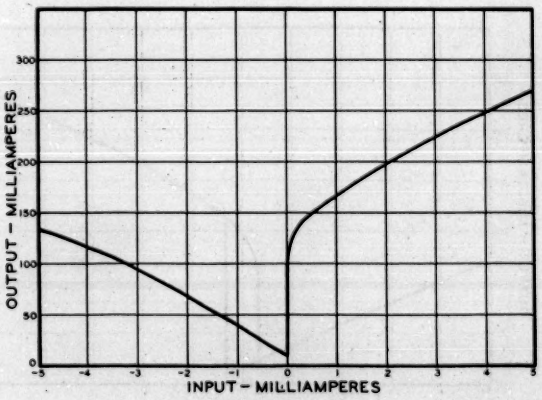

FIG. 12. Response characteristic of amplifier with feed-back and bias windings. Series winding 300 turns.

In the case of magnetic amplifier applications in which the circuit constants are adjusted so as to obtain binary stability characteristics as in Figs. 5, 6, and 7, the bias is also in most cases desirably included. For example, in each of these three curves singular stability obtains at zero input. As has just been described in reference to Fig. 10, by suitably adjusting the bias current, the curve may be displaced laterally to any desired extent. Thus, by employing a suitable value of bias current, we can provide the characteristic shown in Fig. 11 which refers to the amount of feed-back used in Fig. 7 which is 350 turns.

We now have the very interesting result of a circuit which, with zero signal, that is to say, with the input de-energized, has binary stability; it has two quite different output current values either of which repre-

sents a completely stable condition which may be maintained indefinitely in the absence of a controlling signal (6).

In like manner the use of the bias winding is desirable, for similar reasons, if the circuit is to be adjusted so as to furnish the floating control effect. Figure 12 shows the same characteristic as in Fig. 8, with the bias adjusted so as to displace the whole curve slightly towards the right so that the critical floating action now takes place at zero input.

The manner in which the above three phases, or response characteristics, are manifested having now been very briefly outlined, we may now consider some of the ways in which these different action patterns may be utilized in magnetic amplifier circuits. Each phase will be dealt with separately, and further and more detailed descriptive and explanatory data will be presented with particular reference to the several applications.

In order to restrict the volume of this text to reasonable dimensions it will be necessary to limit the scope of this treatment mainly to qualitative description. Principles of design and details of structure and application are of necessity omitted at this time. In this connection it should be stated that the figures given relating to numbers of turns of the series and alternating current windings refer to one particular type of core and to a specific form of rectifier. They are cited for purposes of description and explanation and are not necessarily applicable to all types of circuit design.

SINGULAR STABILITY.

In a previous paper (4) the author described the construction and performance of a group of magnetic amplifiers. In some of these units feed-back windings were incorporated for the purpose of studying the resulting increase in gain.

The above description represents a pertinent example of the use of feed-back in magnetic amplifiers under conditions of singular stability. These data having been already placed on record, further mention thereof need not be made in the present text. For additional details, reference is invited to the above-cited publication.

However, the amplifiers described in the previous paper were intended for applications of the neutral type; that is to say, where, either the response of the amplifier is independent of the polarity of the input signal, or, alternatively, the polarity of the signal is not subject to reversal.

A very brief consideration of the potential field of application of magnetic amplifiers is sufficient to indicate that, in a very large proportion of such possible uses of these devices, something more than a neutral or unilateral type of response is necessary.

Sensitive detecting and responsive devices such as amplifiers are most frequently needed in electrical control systems in connection with

the well-known automatic self-balancing or null type of control principle. That is to say, systems which have a normal condition to which it is desired that they be automatically restored, and which are subject to deviation in either of two directions from the normal; as for example, above or below correct temperature, voltage, frequency or the like. Such systems require that some kind of restoring instrumentality such as might be driven, for example, by a reversing motor, be operated selectively in the forward or reverse direction according to the sense of the deviation; and that the motor be stopped and remain at rest when the normal condition is restored. Two very well known examples of this principle are the familiar potentiometer type recorder and practically all servo-mechanism circuits.

Such systems essentially include either sensitive types of polarized relay, or electronic devices responsive to reversal of polarity or phase (7).

It is clear, therefore, that such systems require a bi-laterally responsive device; one that will respond selectively in accordance with the direction of deviation, and which will also have a null or zero position to indicate that the condition is normal.

For example, if a polarized relay is used it will have a central or normally open position when de-energized, and will deflect in one or other of two directions, operating either of two contacts, according to the input polarity. Such types of polarized relay are usually referred to as giving three-position type control.

The use of the feed-back principle in magnetic amplifiers, under the condition of singular stability, may be utilized so as to realize a magnetic amplifier having a polarized response action of the three-position type analogous to that of a polarized relay. These polarized types of magnetic amplifier are capable of extremely high sensitivity, considerably surpassing the performance in this respect of the neutral type amplifiers described in the above-cited previous paper.

PUSH-PULL TYPE POLARIZED AMPLIFIERS.

By the use of saturating reactors with feed-back windings, in pairs, results closely approximating the type of action of a three-position polarized relay are possible.

Figure 13 shows a typical arrangement (2). Two saturating reactors, complete with feed-back and bias windings in accordance with Fig. 9, have their outputs connected to two resistors, both having the same resistance value. The two resistors are joined together at the negative extremities. In order to make this connection possible both reactors must be supplied from separate a-c. sources. An isolating transformer having two secondary windings is therefore furnished for this purpose. Both bias windings are connected in series and supplied by a single, separate, rectifier.

The two input windings are connected in series in opposite sense; that is to say, if the m.m.f. due to one of the input windings is additive with respect to the m.m.f. of the series winding, the m.m.f.'s of the input and series windings on the second reactor are in opposition. Each bias winding is connected so that it opposes the series winding.

It will be apparent on inspection of this diagram that if the outputs of both of the two reactors are exactly equal there will be no voltage difference between the ends of the two resistors.

Two terminals are accordingly connected thereto and the output of the amplifier is withdrawn at these terminals. Thus if we connect a load circuit, in series with a central-zero type milliameter, to the output terminals, when there is no input, the currents in the two resistors are equal, and no voltage difference appears at the output terminals. The output meter therefore reads on zero.

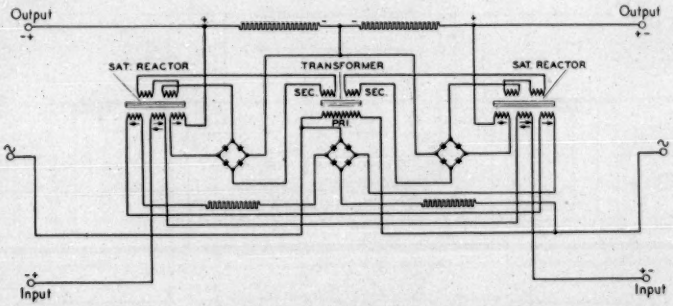

FIG. 13. Push-pull polarized type magnetic amplifier.

If, now, we apply a small current to the input circuit, one of the amplifier elements will receive a positive signal and the other will receive a negative signal. If we refer to Fig. 4, it is apparent that this will have the result of increasing the current in one of the resistors and decreasing that in the other resistor, and the output meter will now show a deflection.

If the right hand input terminal be made positive with reference to the left hand terminal, the current delivered by the right hand amplifier element will be increased and that of the left hand unit will be decreased. Accordingly the right hand output terminal will become positive in respect of the left hand output terminal.

If the direction of the input excitation be reversed the polarity of the output will likewise reverse.

It will be noted that the function of the two resistors in Fig. 13 is analogous to that of the coupling resistors in a push-pull type electronic amplifier.

As shown in Fig. 13 the two bias windings are supplied, in series with a current limiting resistor, from a rectifier which is energized, in series with a second resistor, from the a-c. source. A gain control effect can be obtained by adjusting the value of the current which flows in both bias windings. On referring to Fig. 4 it will be noted that the slope of the output current curve has a maximum value a little to the left of the input zero axis. The gain will be a maximum when the bias current is adjusted so that the two amplifiers are operating on that portion of the curve.

The purpose of Fig. 13 is to present the general principles of this type of magnetic amplifier in a direct and simple manner. Thus only the essential functional elements are shown in Fig. 13. Figure 14 shows a complete diagram of such an amplifier including, in addition to the gain control a zero adjustment feature as well.

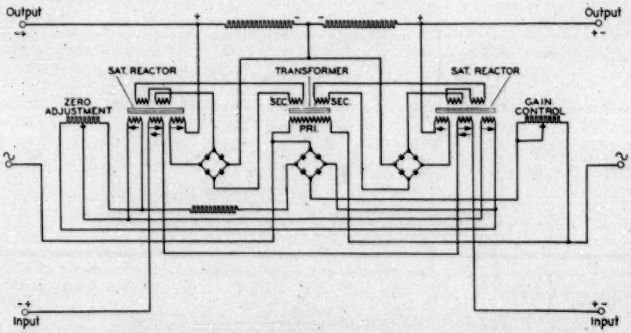

FIG. 14. Polarized magnetic amplifier with gain control and zero adjustment.

The zero adjustment is to permit of accurate balancing of the pair of magnetic amplifier circuits so as to compensate for any inequality of structural components such as resistors, rectifiers, etc. In Fig. 14 a potentiometer-type adjustable resistor is connected in parallel with the two series-connected bias windings. That is to say, the sliding contact of the potentiometer is connected to the common point of the two windings; the two ends of the potentiometer resistance element are connected to the two other extremities of the bias windings.

Thus the two sections of the potentiometer resistance form two shunts which, when the potentiometer is in mid-position, divert equal amounts of current from each bias winding. When the potentiometer is operated in one direction or the other, the current in one bias winding is very slightly increased while that in the other is, at the same time, decreased. This has the effect of displacing the output current curve of Fig. 4 in opposite sense in respect to each of the two magnetic

amplifier elements. This increases the current in one coupling resistor and decreases that in the other, thereby deflecting the pointer of the output instrument to the right or to the left according to the direction in which the knob of the potentiometer be turned.

In this way the output meter, when there is no input to the amplifier, can be set exactly to zero by turning zero adjustment control in the proper direction as may be needed.

Only a single stage is illustrated in Figs. 13 and 14. However, the arrangement of the circuit is such that any number of separate stages may be directly connected in catenation. For example, if a single stage of a polarized amplifier such as that of Fig. 14 be schematically indicated

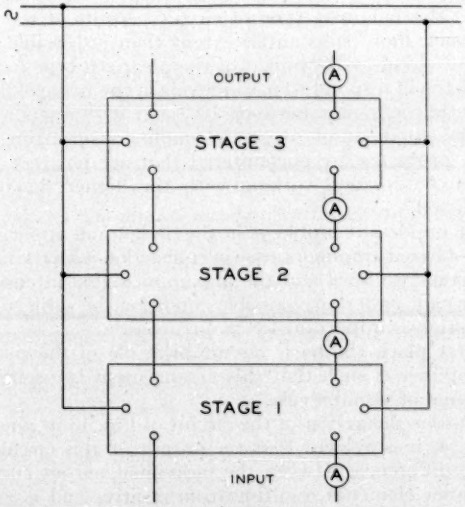

FIG. 15. Three stage polarized magnetic amplifier.

in block diagram form, the power supply, input and output terminals being positioned in a corresponding manner, a three stage magnetic amplifier lay-out would appear as shown in Fig. 15.

It will be noted that when a number of stages are employed, central zero type meters can be included in each inter-stage connection, as well as in the main input and output circuits, as shown in Fig. 15. Thus each individual stage can be checked for zero setting and its functioning studied and supervised. The meters may all be connected with uniform polarity so that they will all deflect in the same direction in accordance with polarity of the signal.

It is of interest to note, in this connection, that the proper bias adjustment should always be such that the individual pairs of amplifier elements, with zero signal, are operating on that portion of the curve of Fig. 4 which lies to the right of the nadir. If, by inadvertence, the bias be adjusted so that the units become operative in the left hand zone of the output curve, the stage so maladjusted will cross over or reverse; that is to say, if, for example, the input meter shows a deflection to the right the output meter will deflect in the reverse direction.

Push-pull type polarized magnetic amplifiers of an order of sensitivity comparable with that of the neutral type amplifiers previously referred to, are no more complicated or critical in use or adjustment than the latter.

However, the balanced type of circuit permits of the use of feedback to a much more substantial extent than is possible in the more simple type of circuit. Amplifiers of the polarized type have been constructed which will respond to power levels in the range of from -60 vu. to -90 vu.; that is to say, between 10^{-9} and 10^{-12} watts.

In the development of magnetic amplifiers operating in this low input range, problems are encountered that are not met with to any appreciable extent when working with the higher signal levels previously discussed.

The most important problems in the design and application of high sensitivity polarized amplifiers arise in connection with the ratio between the normal response level and the maximum signal intensity to which the amplifier can, under any possible condition, be subjected.

This question is important for two reasons.

In the first place the basic circuit principle of the push-pull type polarized amplifier is such that this arrangement is essentially limited to a finite range of signal levels.

If we consider the action of the circuit of Fig. 13 in reference to the curve of Fig. 4, it is evident that the output of this circuit is proportional to the difference between the individual output currents of the pair of amplifier elements resulting from positive and negative signals of equal value.

A study of the curve of Fig. 4 indicates that at first this difference increases with increase of signal level. With further increase in the signal the difference ceases to increase, and with very high signal levels the difference commences to decrease. Clearly this type of circuit will be functional only so long as this difference is manifested. It is of interest to note, however, that despite the above considerations this type of circuit is operative with signal power levels up to several hundred thousand times the minimum response level.

The second reason which involves consideration of maximum possible signal levels is not associated with the nature of the circuit structure but results from the increased sensitivity which is possible with amplifiers of this type.

Subjection of magnetic amplifiers to signal levels of high intensity results in hysteresis effects. These effects necessarily become apparent in proportion as the sensitivity is increased. That is to say, the lower the signal level the greater will be the relative magnitude of any given hysteresis effect.

The extent of this effect is quite appreciable in high sensitivity polarized amplifiers. For example, in a typical instance in which the amplifier had a minimum response level of 50 micro-volts, when the amplifier was subjected to a signal of a thousand times this voltage, that is to say, one million times the signal power level, a zero-shift resulted which exceeded several times the threshold value.

Such a zero-shift can readily be erased, and the original zero position restored, merely by subjecting the amplifier to a signal, of suitable intensity, of the opposite polarity.

However, in practical applications of magnetic amplifiers it is necessary, or very desirable, that this difficulty be taken care of automatically.

It has been pointed out above that it is especially in connection with automatic control systems of the self-balancing or follow-up type that polarized amplifiers appear to have particular pertinence. It is, therefore, important to remember that it is an unavoidable condition in such systems that under certain abnormal operating contingencies the amplifiers may be energized with signal intensities greatly exceeding the regular or normal follow-up increment or difference signal level. Such a condition may occur, for example, when a control system is initially connected to the supply source, or is energized subsequent to a power supply interruption, under which circumstances it can happen that the follow-up system may be in a condition of maximum displacement from the null or normally balanced position.

Considerable study has been given by the author to the problems arising from these circumstances and various arrangements have been adapted or devised by means of which these abnormal signal magnitudes may be by-passed or limited, or in some way prevented from adversely affecting the operation of the amplifier.

The use of the non-linear characteristics of dry-disk type rectifying films, connected in parallel pairs in opposite sense so as to give bi-lateral conductivity, as a by-pass device or limiter is well known. However, in the case of selenium films there is no substantial conductivity at voltages substantially less than one volt and in the copper-oxide film some hundreds of milli-volts.

In magnetic amplifier circuits, for any given power level, the signal voltage, and therefore the applicability of a simple limiter, will depend upon the input circuit resistance. In general it may be said that with magnetic amplifiers of any substantial degree of sensitivity, the signal voltage seldom approaches a magnitude at which a simple copper oxide limiter manifests any conductivity.

The use of negative feed-back (2) is an effective means for excluding from the input winding currents high enough to cause hysteresis zero shift. It also improves the speed of response. There is, however, a substantial resultant loss of gain.

One arrangement devised by the author (9) and which may be described as a "blocking limiter" is shown in Fig. 16.

The blocking limiter circuit consists of a resistor connected in series with the input circuit. This resistor is also connected across the output of the polarized amplifier in series with a bi-laterally conducting non-linear film element such as, for example, two copper oxide films connected oppositely in parallel.

The number of films in series is so selected, in relation to the output voltage, that no substantial conductivity occurs when the amplifier receives signals not greatly exceeding the normal working magnitude. When however, the signal level under abnormal conditions becomes very greatly increased—for example, if it is one hundred times or more its minimum response level—the output voltage, being commensurately increased, reaches the order of magnitude at which the limiter passes current. The polarity of the connections to the resistor are made such that, as shown in Fig. 16, the voltage drop, set up thereby across the resistor, is in opposition to the signal voltage.

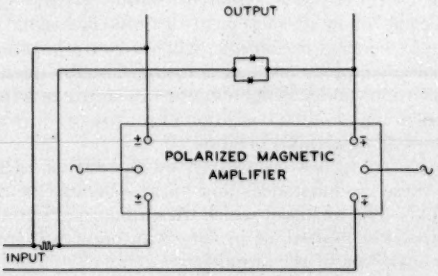

FIG. 16. Blocking limiter.

Accordingly, the action of this arrangement is to block signals of abnormal magnitude. Under such conditions the current in the input winding is limited to values of moderate magnitude such that no substantial difficulty in connection with hysteresis effects is involved.

On the other hand the blocking limiter is entirely inert under normal signal conditions and in no way vitiates the sensitivity of the amplifier.

Only a single stage is indicated in Fig. 16. However, the blocking limiter is particularly effective when it is energized from the output of a second stage.

The blocking limiter, however, is only effective when the circuit is energized and does not give protection if the amplifier can receive an

over-voltage signal, of a magnitude likely to cause hysteresis difficulties, when it is de-energized as, for example, due to system power interruption.

In many instances however, the signal itself may emanate from a device likewise electrically energized from the same power source in which case no such signals can arise under this condition.

For reasons of space, further and more detailed description of these methods cannot be given here. However, to indicate the extent of the progress which has been made in the solution of this problem it may be stated that amplifiers of the polarized type have been constructed capable for properly responding to a signal of 20×10^{-12} watts following the application of a strong signal sixty thousand times greater than this value.

In concluding this discussion of the use of feed-back under conditions of singular stability it may be pointed out that it is not possible to present any definite figures as to the amount of increase in output or gain that can thereby be attained.

The reason for this is that as the gain is increased by appropriately adjusting the circuit constants to this end (it has been pointed out above that increasing the feed-back does not necessarily cause an increase in the gain), a condition is in due course reached in which each increment in the circuit adjustment results in greater and greater increase in gain accompanied by commensurate impairment in the stability; that is to say, in the ability of the amplifier to "reset" or be restored to the previously prevailing condition, following withdrawal of the signal.

In the absence of any definition as to acceptable or unsatisfactory stability characteristics it is impossible to say just how much increase in gain resulting from the use of feed-back, can be achieved. This will depend upon the conditions obtaining in individual applications and will be mainly determined by maximum signal exigencies of the nature discussed immediately above.

In other words, there is no line of demarcation between the action of Fig. 4 and of Fig. 8. Between these two conditions there is a penumbral zone characterized by a marked increase in gain, and dynamic response characteristics of doubtful acceptability.

(To be continued in the May issue of this Journal.)

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(4) ALAN S. FITZGERALD, "Magnetic Amplifier Characteristics Neutral Type," *Ibid.*, Vol. 244, No. 6 (1947). See Fig. 2.
(5) ALAN S. FITZGERALD, "Some Notes on the Design of Magnetic Amplifiers," *Ibid.*, Vol. 244, No. 5 (1947). See p. 349.
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Westinghouse Helping Build "Knockout Punch" for World's Largest Atom Smasher.—The Westinghouse Electric Corporation is building electrical equipment to help pack a six-billion electron-volt "knockout punch" into the world's most powerful atom smasher and enable scientists to carry out studies in the unchartered realm of cosmic rays. The announcement was made by T. I. Phillips, vice president of the company.

Valued at approximately $1,000,000, the electrical apparatus will be installed on the $9,000,000 "racetrack atom-smasher" to be built on the Berkley campus of the University of California.

The new machine will be 17 times more powerful than the University's present cyclotron, which is the largest known to exist today. It is being constructed with funds provided by the Atomic Energy Commission under its pure research program.

The heart and nerve center of the new atom-smasher—called a bevatron—will be the electrical equipment, consisting of two alternating current motor-generator sets; Ignitrons to change alternating into direct current electrically; and a network of controls and meters to channel the power into a giant 10,000-ton circular steel magnet.

In a rectangular "tunnel" in the giant magnet, sub-atomic particles, called protons, will be accelerated by electrical "kicks" until they travel at nearly the speed of light—180,000 miles a second. The protons then will be "fired" into a block of graphite, or compressed gas, smashing the atoms in the material and releasing electrons, neutrons, protons and mesons which make up the atoms. These can be photographed for later study.

Through such studies, scientists hope to find out what holds an atom's nucleus together and whether matter can be created from energy.

To keep the proton "bullets," on their course, the two motor-generator sets together will develop a peak of 100,000 kilowatts of power. If this peak power could be sustained, it could supply all the electrical requirements of an average community of 200,000 persons.

The 50,000 kilowatt generators themselves will be by far the largest and most powerful of their type ever built, Mr. Phillips said. Because of the novel requirements, each generator will have 40 per cent more copper than a standard generator of the same rating.

In operation, Mr. Phillips explained, each generator will be driven by a 3,600 hp. electric motor through a flywheel arrangement similar to that used in steel mills. In this equipment a 75-ton flywheel is mounted on the shaft connecting motor and generator. Spinning at 900 revolutions a minute—the speed of its outside edge will be 350 miles an hour—this flywheel stores up an enormous amount of energy. This energy will supply the extra "push" required for each cycle of operation when the heavy load is on the generator.

From the generators, alternating current power will be fed to a battery of Ignitrons which are electronic "valves" that allow power to flow in only one direction. These Ignitrons thus will convert alternating current electricity into direct current, which, in turn, will be pulsed in a series of short bursts into the huge magnet. The electrical bursts will provide the force necessary to keep the proton "missiles" on their course as they work up to top speed.

TECHNIQUES OF EDITORIAL RESEARCH IN ELECTRICAL ENGINEERING.

BY

HERBERT B. MICHAELSON.[1]

ABSTRACT.

This survey of the literature on research writing describes a procedure for supplementing laboratory work with a search of engineering and scientific publications. A systematic method is suggested for locating literature sources, collecting and classifying notes, and incorporating the material into a research paper. Editorial research is shown to be of value in preventing duplication of effort in laboratory investigations.

1. INTRODUCTION.

In every phase of research and development in the field of electrical engineering there is a well-defined need for searching and interpreting the technical literature. One of the first steps in any research project should consist of an extensive review of previous related work. An ideal survey of this type provides a historical background of the investigations, a comparison of experimental procedures, and an analysis of published results. Since the compilation of this type of information will often prevent duplication of effort, the engineer generally attempts to make at least a brief search for pertinent data and opinion before he starts the actual laboratory work. When confronted with the volume and complexity of modern engineering literature, however, he frequently finds that he has neither the facilities nor the inclination to prepare an extensive survey of published work. Because this neglected aspect of research (1)[2] requires investigating, selecting, and editing the findings and opinions of others, it is referred to here as "editorial research."

The literature search and the subsequent written report should, then, be an integral part of a research project. But many engineers either have not been adequately trained in these techniques or have not the opportunity to spend weeks or months searching in the literature. Accordingly, a research worker often hastily scans some of the available literature to uncover a few leads, and then "with a prayer, a hope, and a few notes, he hurries back to his laboratory to prepare for the performance of his task" (1, p. 188). In many cases the need for assembling the information can best be filled by full-time searchers who are capable of understanding, abstracting, and analyzing the literature as a supplement to the usual preparations for laboratory research.

This paper will discuss some of the methods of conducting a literature search, of selecting and arranging the useful material, and of writing

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

the survey in an acceptable form. Inasmuch as there is no complete agreement among the various authorities on many of the details, and since the best method for any particular writer depends somewhat upon his own thinking processes, the procedure outlined here is intended to serve only as a general guide. In addition, the preparation of this paper itself will be cited here as an example of use of the techniques of editorial research, even though the treatment of the subject is limited both in length and in scope.

2. THE LITERATURE SEARCH.

Since related sources of information are widely distributed among the many branches of engineering and scientific literature, the search, to be of any real value, must be carried out thoroughly and systematically. A half-hearted, casual search will almost invariably fail to uncover highly pertinent information. A system of first turning to comprehensive reviews of the subject and then proceeding to more specialized phases has been suggested by Jones (2). Dividing technical publications into three categories, Jones proposed the following order of search:

Encyclopedic works	(preliminary review)
Specialized books or monographs	(detailed survey)
Articles in periodicals	(specific information)

An inverse method can also be used, according to Jones, by first compiling as complete a bibliography as possible from the articles and then working back to the more fundamental reviews. The former method, which is similar to the process of deductive reasoning from the general to the specific, is probably better adapted to most types of search.

In the initial preparation of a bibliography, the searcher must turn to the various indexes and catalogs of engineering literature. Because systems of filing, cataloging, and classifying have definite limitations, they present a challenge to the searcher who attempts to ferret out the desired information. For the more fundamental aspects of a technical subject, the listing under that topic in several encyclopedias (3, 4, 5) and handbooks (6, 7, 8) can be useful. Among the best sources for compiling a bibliography of specialized books and monographs are the subject entries in the main card catalog of a large library. Several book indexes (9, 10, 11, 12) are also helpful in this respect. After the basic bibliography has been compiled, an examination of these books will generally reveal lists of references on the subject that the several authors themselves have compiled. Not too much reliance should be placed, however, upon the completeness of these lists. The remaining, and usually the most fruitful, sources of specific information are the indexing and abstracting services for periodical literature.

Inasmuch as none of these services covers the same group of periodicals, any single guide to the literature must not be considered complete

in itself. Neither *Science Abstracts* (13) nor *Physikalische Berichte* has "anything like complete coverage" (14) of physics and engineering articles. The use of *Chemical Abstracts* will often help considerably in building up a bibliography on electrical engineering subjects. Nevertheless, out of the 750,000 scientific articles that appear annually in 15,000 periodicals, only one third are abstracted (15). An additional search through the annual issues of *The Engineering Index*, *The Industrial Arts Index*, and through the *Electronics Engineering Master Index* will usually yield a large number of references. *The Monthly Catalog of U. S. Government Publications* may also indicate good sources of information.

A search for references is complicated by the differences in terminology encountered in the indexing and abstracting services, and different methods of classification present a problem to the searcher who attempts to locate the many sources of information. For example, reference material for this paper was found in the *Engineering Index* under the topic of "Engineering Writing," in the *Industrial Arts Index* under "Technical Writing," in the *Readers' Guide to Periodical Literature* under "Authorship" and in a library card catalog under "Research Writing." The quest for literature sources is obviously not a simple process of going to an index or catalog and looking for references under a given subject heading; rather, it is a sleuthing job. Glittering nuggets of engineering information often lie hidden in the literature where the searcher would least expect to find them, and only a careful seeking, sifting, and sorting will reveal their existence. The searcher who is prospecting for information will experience many disappointments from misinterpreted titles, but he will also stumble upon valuable data from unexpected sources. A search that to the uninitiated may seem to be a boring, tiresome task may often be an exciting hunt for information that can mean all the difference between success and failure of a research project.

3. SELECTION OF MATERIAL.

After the bibliography has been listed either on a sheet of paper or on separate file cards, a preliminary survey, referred to by Parke (14, p. 8) and Holmstrom (16) as a "reconnaissance," should be made of the available material. Since titles are often misleading, they are of little value in sorting out the more useful references. The best way to determine the relative merit of the articles is to consult some abstracting service such as *Science Abstracts*. For those references that have not been abstracted, the original published work must be obtained. In the case of a book, the table of contents, the preface, the introduction, and the index will give a quick indication of the contents. For magazine articles, the best guide is the summary that usually appears either at the beginning or the end. From comparative reading of abstracts and summaries, the more important references can be

identified and selected for use. Since the basic structure of the research paper is to be built from the content of these source references, careful judgment and discrimination is necessary in their selection.

When the more important references have been chosen, the original records should be consulted in each case; too much reliance should not be placed upon abstracts. In examining these books and articles, rapid reading and quick analysis is of prime consideration. The searcher will rarely have time, however, to read every word or even every paragraph of each of a large number of references. He must pass quickly over the passages which seem to be least relevant to his topic, and must devote careful study only to those portions to which he will actually refer in his research paper. This phase of editorial research demands the most of the reader. His ability to recognize the important relationships between the source material and his research topic will be the very basis of a fruitful search.

The searcher must not trust his memory for quoting information he has located in the literature, nor can he work well with a large quantity of disorganized notes. Because every experienced research worker has his own favorite system of taking notes, and since any system must be adapted to the requirements of the subject, no attempt will be made here to prescribe a rigid, inflexible method of taking and classifying notes. Certain broad principles cited by several authorities will, however, be recommended.

Notes should be written on file cards or on loose-leaf sheets of paper for convenience in sorting and classifying. Ruled cards 3 by 5 in., 4 by 6 in., or even larger are used, and half sheets of note paper have also been recommended. For any kind of technical research writing, the best procedure is to copy pertinent sentences verbatim from the published work and to use a separate card or sheet of paper for each entry, writing on one side only. Checking each quotation twice against the original text is a wise precaution. A topical word or phrase is written on the top line in order that the cards may later be sorted and arranged in subject groups according to the sequence of ideas (17). An example of a note card is given below:

LITERARY STYLE R5

P.99 "The use of emotive language, especially to gain an important point, will usually be resented by the specialist, who needs no program notes to tell him when and what to feel."

Instead of identifying the source by writing on the card the name of the author and other necessary information, the code number "R5" is used. When it becomes necessary to refer to the source of the note, the fifth source on the bibliographical list is found to be

(R5)D. Roller, "Technical Writing and Editing: Source Literature, Elementary Textbooks," *American Journal of Physics*, Vol. 13, pp. 99–105 (1945).

When all reading material and the cross references have been examined and noted, and when the cards have been divided into groups of related subjects, an outline of the paper can be drawn up. Where the research worker had been thoroughly familiar with the subject before starting the search, he could have first made a rough outline and then taken notes according to the topics in his outline (18). Regardless of method, the outline is a flexible structure that must be adapted to the shifting trends of thought of the author. Only after a final outline has been decided upon and the necessary information accumulated should the writing of the research paper be started.

4. THE RESEARCH PAPER.

The first rough draft should be written rapidly, with little concern for literary style. Too much attention to grammar and rhetoric will only serve to interrupt the flow of thought. Instead, emphasis should be placed upon accuracy. Since the research paper is based on source material, the interpretations must be presented carefully and should be documented properly with footnote references. Moreover, a distinction must be made between fact and opinion. Although a review of the literature is usually objective, editorial research need not be entirely so. The main purpose of the latter type of research paper is not only to present pertinent data in an accurate manner but also to show how published information is related to a particular research project or how it can contribute to the solution of an engineering problem.

If this information gathered from a wide variety of sources is to be presented in an effective fashion, some semblance to scientific method should be in evidence, and the ideas should appear in logical succession. The order of presenting these ideas may be from the simple to the complex, from the known to the unknown, in order of importance, or in some spatial or temporal sequence (19). While sound organization is essential to any good piece of writing, it is particularly so for engineering and scientific literature. Even though the structure is closely knit and the order of presentation is logical, the effectiveness of a research paper can be still further enhanced if the proper emphasis is placed on its component parts. The space devoted to the various ideas should be proportionate to their relative importance.

After the first rough draft has been written, it should be revised by improvements in the sentence structure and choice of words because the net worth of the article will depend "almost as much on the clearness

and completeness of presentation as on the accuracy of the data and the intelligence with which they are interpreted" (20). The author must accept the responsibility of making his meaning unquestionably clear. The tone, too, should be factual. The use of emotive language "will usually be resented by the specialist, who needs no program notes to tell him when and what to feel" (21).

Although no attempt should be made to do the reader's thinking for him, it is legitimate and even necessary to capture and sustain his interest by several well-known devices. The first and most important of these is placing a topic sentence at the beginning of each paragraph to give the reader a clear hint of what is to follow. Another device is the use of connecting words and phrases that afford a smooth transition from one thought to another and thus guide the attention of the reader into integrated channels of thought. Usual word order will sometimes be effective in maintaining interest in what would otherwise be dull, wordy passages. Whatever device is used, the author must lead the reader along a well-defined path of reasoning, rather than try to tempt him along with provocative words and phrases. When the author has finally reached his objective near the end of the paper, he should not fail to take his cue from the relationships shown in the body of the article and to sum up briefly in a strong conclusion or discussion.

Reader interest can be maintained by the physical appearance of a report as well as by a good rhetorical style. The exact form will depend largely upon the nature of the report and the requirements of its recipient, but as a general rule, clean typing, double spacing on white paper, and wide margins are desirable. An abstract at the beginning, a table of contents, underscored headings, and a complete bibliography will all be of value to the reader. If the article is written for publication, its physical makeup should conform to the particular requirements of the periodical. Several technical magazines have published their specifications either as articles (22, 23) or as brochures (24).

There is a great lack of uniformity in the style of bibliographic citations, as pointedly discussed by Walter (25). The forms used in this article, however, are representative. As for the method of citing them, some publications place the footnote references at the bottom of each page and others put them at the end of the article. In other cases, a complete bibliography appears at the end of the article in addition to the footnotes. Whichever style of reference citation is used, it should serve its purpose of presenting enough information for positive identification of the source.

5. CONCLUSION.

In correlating and integrating information found in the literature, editorial research can save a great deal of money, time, and effort in practically any kind of laboratory research and development. While

the techniques of editorial research are well adapted to relating published material to a specific laboratory project, they are also useful in the preparation of review articles for general information about a given phase of electrical engineering. Since publication of results is now more active than ever before, the missing link for an engineering problem may be found in some obscure corner of the literature off the beaten paths of research.

If the research paper is written by a specialist in literature search, laboratory investigations may be stimulated by a new slant on the topic. If, on the other hand, the laboratory worker has the opportunity to conduct an extensive search and to write the report himself, this work will help to crystallize his own thinking and to clarify his research problem. The creative functions of reading and writing may be summed up effectively by Francis Bacon's observation that "Reading maketh a full man, conference a ready man, and writing an exact man" (26).

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Driverless Truck.—What might be the industrial truck of the future—a driverless fork truck operated by ray control—was demonstrated recently at the Third National Materials Handling Exposition, in Philadelphia, by the Automatic Transportation Company, Chicago manufacturer of materials handling equipment.

No explanation was given of how the ray is used to drive the truck. It was explained that radio cannot be used, because radio frequencies for such a unit are unavailable.

A compact unit designed for handling loads of about three-quarters of a ton, the machine already has aroused considerable speculation as to its potential use.

Despite the empty driver's seat, the truck performs all customary functions of a lightweight materials handling machine. Except for its unique control system, it is a standard model of a new machine being shown for the first time by Automatic.

The operator, hidden behind a one-way vision glass screen, is able to see the entire floor before him. Using a panel of dials and buttons, he guides the vehicle through its entire "look—no hand" routine. Without assistance the unit picks up a capacity load, carries it to the other end of the work area, raises it as high as 134 in. above the floor, and stacks it as merchandise would be tiered in a warehouse or factory.

Some experts see in the truck the basis for a materials handling system which would combine remote control with television. Such an operation, they feel, might be feasible where the work involved is standardized and there are few other activities in the same area which could complicate the system.

Automatic officials have made no predictions about remote-controlled materials handling for the future. The vehicle on display was designed, they said, to show visitors how far technology can go in relieving the burden or muscular exertion so long carried by men.

Radiotelephone Communication.—Radiotelephone communications by ships on the high seas with shore points and other ships have been made easier and more reliable by a new 250-watt radio equipment, the Western Electric 248A marine radiotelephone. The design and operating principles of this equipment were featured recently at the National Motor Boat Show in Grand Central Palace, New York City. When a ship having this equipment is travelling principal world trade routes, two-way calls can be made between the ship and regular land telephones. Thirty transmitting frequencies are provided, three from each of the ten marine service bands between 2100 KC and 18000 KC.

Designed by Bell Telephone Laboratories for steamship companies and private individuals desiring two-way radiotelephone communication on ocean-going ships of all types, the equipment is arranged so that persons not having special radio knowledge can easily make calls. It is especially adaptable for cargo vessels, oil tankers, and small passenger ships for which sufficiently powerful radiotelephone equipment of convenient size has not been available before.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

THE ATOMIC CLOCK.

AN ATOMIC STANDARD OF FREQUENCY AND TIME.

A basically new, primary standard of frequency and time, invariant with age, has been developed at the National Bureau of Standards; an atomic clock based on a constant natural frequency associated with the vibration of the atoms in the ammonia molecule. Based on a principle developed by Dr. Harold Lyons of the Bureau's microwave research laboratory, the new clock promises to surpass by one or two orders of magnitude the accuracy of the present primary standard, the rotating earth. Dr. Lyons was assisted in the design and construction of the clock by B. F. Husten, E. D. Heberling, and other members of his staff.

This is the first atomic clock ever built and is controlled by a constant frequency derived from a microwave absorption line of ammonia gas, providing a time constancy of one part in ten million. Theoretical considerations indicate a potential accuracy of one part in a billion or even ten billion, depending on the type of atomic system and spectrum line used.

The present crowding of the radio frequency spectrum has imposed severe limitations, both nationally and internationally, on the expanding use of radio for industry and communications. The atomic clock may be expected to benefit greatly the communications industries and the military services, for it will, in effect, provide additional room in the radio frequency range for more communication stations of all types. The present "radio space" allows for a drifting of each station's frequency, so that a broad "radio space" is required if interference with other stations is to be avoided. The maximum utilization of available space in the radio spectrum depends on the accuracy with which the frequency of an individual station can be controlled, especially at the higher frequencies where quartz crystals cannot be used as frequency controlling elements. These frequencies, used by radar, television relays, and microwave equipment in general, could be controlled by atomic elements. Such control would also make possible the permanent establishment of radio channels on such an exact basis that tuning could be made as automatic as the dialing of a telephone number.

The improvements in frequency and time measurement offered by the atomic clock are also of fundamental importance in many fields of science. An absolute time standard will be of special importance in astronomy, where present time standards leave much to be desired.

* Communicated by the Director.

The atomic clock and the method represent important tools of research and development in every technical field where precise measurements of time and frequency are crucial—for example, in long-range radio navigation systems, in the upper range of the microwave region where atomic systems can serve as electronic components, and in basic research in microwave spectroscopy and molecular structure.

The present time and frequency standards are based on astronomical determinations of the period of rotation of the earth. However, the earth is very gradually slowing down in response to the forces of tidal friction in shallow seas. In addition, there are irregular variations—some of them rather sudden—in the period of rotation, the reasons for which are unknown. These two causes are responsible for changes in mean solar time and therefore in the frequency of any periodic or vibrating systems measured in terms of such time standards.

In recent years, vibrations of atoms in molecules—or what are more specifically termed spectrum lines originating in transitions between energy levels of these atomic systems—have been found in the microwave region of the radio spectrum. It has been possible to make very precise measurements of these lines by radio methods using all-electronic equipment of unprecedented sensitivity and resolution. When it became evident that such spectrum lines might eventually provide new primary frequency standards, scientists at the National Bureau of Standards began seeking a means of utilizing one of these lines to control an oscillator which in turn could be used to drive a clock. Because the resulting equipment, the atomic clock, is controlled by the invariable molecular system of ammonia gas, it is independent of astronomical determinations of time.

The National Bureau of Standards atomic clock consists essentially of a crystal oscillator, a frequency multiplier, a frequency discriminator, and a frequency divider, all housed in two vertical-type cabinet racks, on the top of which are mounted a special 50-cycle clock and a waveguide absorption cell. Ammonia gas under a pressure of 10 or 15 microns is maintained in this cell, a rectangular $\frac{1}{2}$ by $\frac{1}{4}$-in. copper tube wound in a compact 30-foot spiral about the clock.

The new development uses an absorption frequency of ammonia to hold a microwave signal fixed. If the microwave signal output of a generator differs in frequency from the ammonia absorption line, then the control circuits generate an "error signal" which brings the microwave signal back to the frequency of the spectrum line. The oscillator generating the microwave signal is thus controlled, and the setting of the clock which it drives can be compared with an astronomical clock.

The microwave signal is initiated by a 100-kilocycle quartz-crystal oscillator or any other oscillator which, for purposes of convenience and accuracy, is designed for a high degree of stability. By means of vacuum-tube circuits and silicon-crystal diodes, this frequency is

multiplied to provide output signals throughout the microwave range. These signals are compared with the frequency of a microwave spectrum line, in this case of ammonia gas, by suitable control circuits, often called frequency discriminator or "servo" circuits. If the quartz-crystal oscillator drifts after the microwave signal at the upper end of the multiplier chain has been exactly tuned to the frequency of the spectrum line, the discriminator circuit generates an output signal which, through the proper control circuits, can be applied to the oscillator at the bottom of the multiplier chain to bring it back to the proper frequency. By means of a frequency divider, the 100 kilocycles may be reduced to any desired frequency for driving a clock; e.g. one thousand cycles or 50 cycles.

PRINCIPLES AND OPERATION.

Frequency-discriminator or servo-mechanism control circuits for atomic clocks might be developed in many different forms. The electronic control circuit in the present atomic clock is one successful form of several being developed by the National Bureau of Standards. It is now being refined to give even greater time-keeping accuracy.

The fundamental frequency signal generated by the 100-kilocycle oscillator is first multiplied up to 270 megacycles per second (abbreviated Mc) by a frequency-multiplying chain using standard low-frequency tubes. In the next step, the multiplying chain is continued up to 2970 Mc by means of a frequency-multiplying klystron, which is also modulated by an FM oscillator generating a signal at 13.8 ± 0.12 Mc. This makes the frequency-modulated output of the klystron 2983.8 ± 0.12 Mc. After further amplification, the frequency-modulated signal is multiplied in a silicon crystal rectifier to $23{,}870.4 \pm 0.96$ Mc, and fed to the ammonia absorption cell. As the frequency of this modulated control signal sweeps across the absorption line frequency of the ammonia vapor, the signal reaching the silicon crystal detector at the end of the absorption cell dips because of the absorption, thus giving a negative output pulse.

A second pulse is generated when the output of the frequency-modulated oscillator at 13.8 ± 0.12 Mc is fed to a mixer (or radio receiver) into which is also fed a 12.5-Mc signal from the quartz-crystal multiplying chain. When the signal sweeps across the proper frequency to be tuned in (12.5 Mc plus the 1.39 Mc intermediate frequency of the receiver, or 13.89 Mc), an output pulse is generated. The time interval between the two pulses—that from the absorption cell, caused by the absorption line, and that from the receiver or mixer—is a measure of the degree to which the frequency-multiplying chain is tuned to the absorption line. The two pulses can therefore be made to control a discriminator circuit which will give zero output when the time interval is right (that is, when the circuit is tuned to the absorption line) and will

generate a control signal when the time interval is wrong. If the quartz-crystal oscillator drifts in frequency to higher values, the time interval between the two pulses increases; for frequencies which are too low, the interval decreases. The control signals thus generated are fed to a reactance tube, which then forces the quartz-crystal circuit to oscillate at the correct frequency to tune to the absorption line. The quartz-crystal oscillator is thus locked to the ammonia line. Frequency dividers then divide the precise 100-kilocycle signal down to 50 cycles to drive an ordinary synchronous motor clock, and also down to 1000 cycles to drive a special synchronous-motor clock, which is designed for exact adjustment and comparison with astronomical time to within 5/1000 of a second.

Control of the quartz-crystal circuit depends on the relative duration of the positive and negative portions of a square-wave signal generated by the discriminator. In the discriminator, the two pulses between which the time interval is to be measured turn a trigger circuit or square-wave generator on and off. When the time interval is correct, the on-off cycle generates no output signal from the positive and negative peak detectors driven by the square-wave signal. The detectors or rectifiers draw current on the positive and negative peaks of the square-wave, but when the positive and negative portions of the square wave are of equal duration, they balance and give no direct current output. However, if the time interval between the two input driving pulses gets longer or shorter, the relative duration of the positive and negative parts of the square-wave changes so that a resultant direct-current output is generated. This output is positive or negative, depending on the change in the time interval. Thus, no control voltage is generated when the quartz-crystal oscillator is on the proper frequency to agree, through the frequency-multiplying chain, with the ammonia line; but a positive or negative control voltage is produced for correcting the oscillator circuit when it drifts one way or the other from its proper value.

One great advantage of this particular clock circuit lies in the inherent short-time stability of the quartz-crystal oscillator, which makes it unnecessary for the discriminator circuits to apply correcting control signals to the oscillator at a very rapid rate. The crystal and multiplier circuits bridge the gap between the frequency of the clock and that of the absorption line.

Recording equipment and a frequency meter are used in checking the accuracy of the clock. For this purpose, the frequency of the clock's crystal oscillator is compared to the frequency of the Bureau's primary frequency standards, a group of precision, 100-kilocycle quartz-crystal oscillators calibrated in terms of the U. S. Naval Observatory time signals. These oscillators maintain constant frequency with respect to each other to an accuracy of one part in a billion for intervals up to

10 hours and better than one part in 100 million per day. They can therefore be used to measure the constancy of the atomic clock to this accuracy. This is done by beating the signals from the two sources together at a frequency of 12.5 Mc to obtain greater measurement sensitivity. A change of one cycle per second in the frequency of the beat note, as recorded on the frequency meter or on an automatic recorder, indicates a frequency variation of one part in 12.5 million. In recent tests the clock maintained a constancy of one part in ten million for several hours. These tests show that the clock will lock accurately to the ammonia line even when a perturbing signal is applied to the reactance tube in the attempt to force the clock to change its rate.

ULTIMATE ACCURACY.

The ultimate accuracy of an atomic clock depends on many factors, of which the most important are those governing the width of the spectrum line. Spectrum lines are not infinitely narrow but have a finite width covering a considerable frequency range, since atoms or molecules do not emit or absorb radiation at only one frequency but rather over a narrow band of frequencies. The ratio of a line frequency to its width at the half-power points is called the Q of the line, in analogy to the Q (quality) factor of resonant circuits used in standard radio technique. The Q is a measure of the sharpness of the line and therefore determines its usefulness as an accurate frequency and time standard.

In the case of ammonia, the natural line width determined by the uncertainty principle of quantum mechanics gives a Q of about 10^{18} (a billion billion). If a line width were determined only by the natural life time of an excited state in the ammonia molecule, giving a Q of 10^{18}, frequency and time could be determined to better than one part in a billion billion (1,000,000,000,000,000,000). However, the line is broadened by other factors which lower the Q to a value of from 50,000 to 500,000, depending on the temperature and pressure of the gas. This may be compared to Q values of roughly 50,000 for a good cavity resonator in a microwave circuit and values of 1,000,000 or so for the best quartz crystals. The ammonia spectrum line thus has a Q approximating that of the best quartz crystals, though much more constant and stable.

The ammonia molecules in the absorption cell are moving rapidly in random thermal motion at an average speed of almost 2000 ft. per second at room temperature. When a gas molecule in an absorption cell is approaching or receding from the source of an electromagnetic wave because of its heat motion, its absorption frequency is different from that which it would have if it were standing still. This gives rise to a "Doppler broadening" of the absorption line, analogous to the change in pitch of sound as its source approaches, passes, and leaves an observer. Thus, the line width can be reduced slightly by lowering the temperature

of the gas (or by using a heavier molecule). Doppler broadening lowers the Q of the ammonia line to about 330,000 at room temperatures.

Molecular collisions also broaden the absorption line. This broadening occurs because the collisions abruptly terminate the absorption process, causing the molecules to absorb wave trains whose lengths vary in a random way determined by the distribution of time intervals between collisions. A frequency analysis of these wave trains shows a corresponding random distribution of absorbed frequencies, all centering about a mean value determined by the number of collisions per second. In ammonia gas at a pressure of 10 microns there are about 120,000 collisions per second, giving an experimentally measured Q of 45,000 for the absorption line used. (This is the line known to spectroscopists as the 3,3 line, for which the quantum numbers J and K are each equal to 3.)

Actually, there are more collisions effectively interrupting the absorption process in ammonia than the kinetic theory of gases would indicate. Further broadening of the line results from collisions of the molecules with the walls, and even near misses between molecules cause interaction strong enough to interrupt absorption. The number of collisions per second, and thus the collision broadening, can be reduced by lowering the gas pressure. This process, if not carried too far, does not reduce absorption in the gas, because the decrease in number of molecules absorbing energy is offset by the increase in absorption per molecule resulting from the increase in Q. However, when the pressure is reduced too much, a phenomenon known as saturation of the line sets in, caused by an excess of radiation. Too few molecules are then left in the proper energy states to absorb the microwave radiation coming into the cell. Many molecules, which normally would be in the proper energy state to absorb the incoming radiation, are in an excited state as a result of previous absorption. Eventually these molecules will emit the quanta which they have absorbed, returning to the normal level where absorption is again possible. However, as this process is slow, the molecule usually returns to the ground level in a collision with another molecule, converting the absorbed radiation into heat. As the gas pressure is lowered, the number of collisions is greatly reduced, and not enough molecules return to ground levels. The excessive incoming radiation then weakens and broadens the absorption line through saturation. The broadening results because saturation occurs earlier at the peak of the line than out at its wings.

Saturation can be eliminated by reducing the strength of the incoming radiation. However, as the gas pressure and radiation intensity are both lowered, a condition will finally be met for which the signal strength will be down in the natural electrical noise level of the circuits used to detect the signal. Circuit noise then sets the ultimate limitation on the reduction of collision and saturation broadening. It is estimated

that a Q of 300,000 to 400,000 can be attained at pressures of about one micron—still a long way from the Q of the natural line width. Assuming that effective Q values of 400,000 can be obtained with ammonia, an accuracy of one part in 100 million or better should be possible since a measurement of the center of the absorption line to within 1/250 of the width of the line could be made.

APPLICATIONS AND SIGNIFICANCE.

Improvement of the accuracy of the atomic clock will make it useful in several fields of pure and applied science. The lengths of the mean solar day, used in astronomical measurements, fluctuate as much as one part in 20 to 30 million, because of variations in the rate of rotation of the earth on its axis. The variation in present time standards, due to these fluctuations, causes errors in the location of heavenly bodies and in studies of their orbits and motions. The atomic clock offers the possibility of an invariant master clock against which the variation in the earth's time-keeping could be measured. An absorption cell on an atomic clock could, for some purposes, take the place of an astronomical observatory.

Broadcasts of standard frequency are of importance in keeping all kinds of radio, radar, and electronic equipment properly tuned throughout the world. This service is required in international transportation and communications so that, for example, an airplane with radio navigational equipment will be using the right frequency wherever it is in the world and whatever airport it is using. At present, the National Bureau of Standards Station, WWV, broadcasts standard frequency and time signals on several transmitter frequencies to all the world. The Navy Department also uses quartz-crystal clocks to broadcast time signals for navigational purposes. These quartz-crystal clocks drift slightly in frequency and have to be adjusted to keep them in agreement with the basic astronomical time signals. Clocks of this type could be kept constant automatically by means of absorption lines.

Maintenance of transmitter frequency to within close limits is also necessary to utilize the available radio spectrum efficiently. The use of long-distance standard frequency broadcasts is complicated by a large reduction in accuracy due to ionospheric effects. A long distance, short-wave signal travels around the earth by reflection from the upper ionized regions of the atmosphere, known as the ionosphere. Every morning at sunrise the ionosphere moves downward, and every evening at sunset it rises. This daily variation in height causes a Doppler shift of the frequency of the reflected wave and, together with other as yet unknown causes, is responsible for a reduction by a factor of 25 or more in the accuracy of the frequency of the received signal. Thus, the Bureau's standard frequency broadcast agrees with astronomical time signals to one part in one hundred million at the transmitter but

may be known to only one part in four million after transmission over long distances. This difficulty can be partly overcome in several ways. One is the provision of a local, precise frequency standard calibrated by means of received standard time signals also transmitted by radio. However, this process, which requires a day or more, complicates the equipment problem and introduces additional errors, making impractical the use of standard frequency broadcasts for instantaneous or continuous frequency calibrations of the highest precision.

At the last International Radio Conference held in Atlantic City in 1947, plans were formulated to provide standard frequency and time broadcasts from many stations located to render good service throughout the world. These services may be improved or simplified by means of atomic clocks and frequency standards. Such clocks could control the standard frequency emissions of the various stations without checking and monitoring by astronomical time signals. The Doppler frequency shifts could then be eliminated by limiting transmission distances to short ranges. Also, equipment anywhere in the world could be checked against an absorption line with the certainty of obtaining a precision calibration against an absolute standard and without depending on a standard frequency broadcast.

One advantage of the rotating earth as the basic time-keeper is that it never stops rotating or breaks down. Likewise, any man-made clock must not break down but must be kept running forever if it is to keep track of time from some arbitrary instant chosen as a starting point. With the present quartz-crystal clocks, this difficulty is met by using a large number of similar clocks constantly intercompared so that breakdown of one does not mean a loss of time-keeping records. While this procedure could also be used with atomic clocks, it would not be necessary for use of the clock as a frequency standard or for defining a standard of time-intervals since these applications do not require continuous operation of the atomic clock.

The atomic clock should permit improvement in astronomical time standards in a way impossible with electric-pendulum or quartz-crystal clocks. It thus opens the possibility of improving the precision of knowledge of the length of the year, that is, the time it takes the earth to revolve once in its orbit around the sun. This is independent of the time it takes the earth to rotate once on its axis—the mean solar day. Measurements could then determine whether the mean sideral year is more constant than the mean solar day, as some astronomers believe may be the case.

Although the use of atomic time presents advantages in many fields of science, it will always be necessary for some purposes to have astronomical time standards. This is because the pointing of a telescope depends on the orientation of the earth at the instant of observation, in other words, on astronomical time measurements which derive from the motion of the earth.

THE FRANKLIN INSTITUTE.

STATED MONTHLY MEETING, WEDNESDAY, FEBRUARY 16, 1949.

The Stated Monthly Meeting of The Franklin Institute was held on Wednesday evening, February 16, with Mr. Richard T. Nalle, President, presiding. There was a capacity house in attendance.

The President stated that the minutes of the Stated Monthly Meeting for January were printed in full in the February issue of the JOURNAL OF THE FRANKLIN INSTITUTE and would stand approved as printed if there were no dissent. The President then asked for a report from the Secretary, but the Secretary had no announcements to make.

At this meeting, the first of the "Edward G. Budd Lectures" was presented. This foundation has been established by Mrs. Edward G. Budd, Sr. and Mr. Edward G. Budd, Jr., to be presented "in the field of the manufacturer's social and financial responsibilities to the owners of the business, the employees, the local community, and the general public, together with associated technical problems," in memory of the late Edward G. Budd, Sr., who during his lifetime was vitally interested in these subjects.

The President presented Dr. George L. Kelley, Deputy Chairman of the Pressed Steel Company, Ltd., Oxford, England, who was the speaker of the evening. Dr. Kelley spoke on the "Life and Work of Edward G. Budd." Dr. Kelley's talk will be published in full in a subsequent issue of the JOURNAL.

HENRY B. ALLEN,
Secretary.

ACTIVE MEMBERS ELECTED AT THE MEETING OF THE BOARD OF MANAGERS FEBRUARY 16, 1949.

ACTIVE FAMILY.

James E. Booth

ACTIVE.

Paul E. Boyle, D.D.S.
David A. Colker
Warren T. Edwards
Herbert P. Harkins, M.D.
Melvin C. Howell
Boland Hughes, M.D.
John J. Hunt
Clyde R. Joy, Jr.
Jacob J. Kirshner, M.D.
James M. Large
Walter A. Lausterer
John A. Luders, M.D.
David S. Madsen
Sven Richter
Albert B. Sample
William C. Schneider
W. J. Sommer
Henderson Supplee, Jr.
Theodore R. Yoos
Abraham A. Zappel
Walter J. Zera

ACTIVE NON-RESIDENT.

W. A. Nichols
Andrew Sinnickson

NECROLOGY.

Victor D. Abel '43
Thaddeus L. Bolton, Ph.D. '37
J. M. Emerick '22
James Gillinder '41
Frank M. Hardt '36
Miss Bessie Harvey '36
F. M. Kirby '36
Robert L. Montgomery '36
L. Rodman Page '36
Richard Sellers '84
J. B. Tomlinson '43
Luther Weitzel '46
Mrs. James M. Willcox '37

MUSEUM NOTES.

A TRIP TO THE MOON.

The date is 2033. The time is late in March. After almost a century of experimentation man has finally evolved a rocket ship to carry him to the moon. During the second World War there was a resurgence of rocket activity and in the decades that followed man was able to launch rockets and control them and finally achieve a point where the rocket could leave the earth and be controlled.

The passengers for this first trip have all been carefully chosen and comprise engineers to check on the performance of the rocket ship, both at launching and landing, astronomers, geologists, mineralogists and others who will attempt a very careful first hand study of the lunar conditions and the necessities which will be required to enable future explorers to live on the moon.

Those who will actually set foot on the moon have been trained in the technique of walking under odd conditions. With a surface gravity of only a sixth of that on the earth, a 180-pound man will weigh only 30 pounds, and every ordinary muscular effort will result in a six-fold response. He will be able to jump 20-odd feet, vertically, and to take strides equally long.

When the explorer gets down on the surface of the moon he must be fully protected from the lethal radiation of the sun. The ultraviolet radiation of the sun is as lethal to man as being caught in the blast of an atomic bomb. Space suits with plastic helmets to absorb this radiation will be necessary. Incorporated in the space suits will be a device for regenerating the oxygen supply of the explorer because of the complete lack of an atmosphere on the moon.

Because of the lack of an atmosphere the moon has no sky. As the sun's light passes through our atmosphere the blue light is scattered in all directions, reaching our eyes from all parts of the sky, producing the blue dome we see overhead. With no atmosphere there can be no scattering and the sky will remain black when the sun is shining.

The lack of an atmosphere will produce another curious effect. Sound waves cannot travel in a vacuum, hence the explorer will hear nothing even though you try shouting in his ear. The only method of communication on the surface of the moon will be by short wave radio. Even with the short wave radio the lack of an atmosphere will mean that if the explorer gets too far from the spaceship signals will have to be sent to the earth and then relayed back to the explorer on the moon.

The sun will come above the horizon and will slowly move across the sky. It will take almost 15 earth days to do this, for the day on the moon is equal to the month. The earth will be seen in the sky, and it will present a peculiar sight, since it will appear to be stationary. The sun will move past it, the stars will move past it, but the earth will remain in a particular part of the sky without ever changing its position. The only way in which the earth will change its position in the sky is for the explorer to move over the surface of the moon.

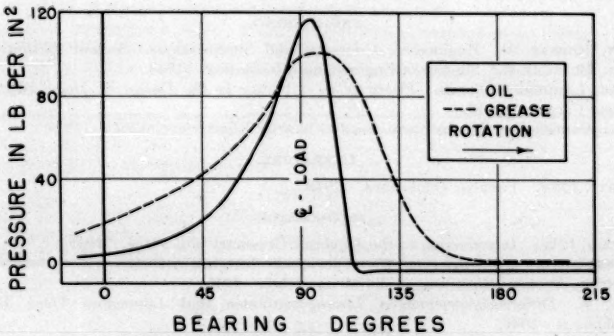
Without an atmosphere on the moon that pearly halo of light seen around the sun only at the time of a total eclipse will be visible at all times. Even the most assiduous eclipse chasers on the earth never get to see the corona for more than an hour in their entire lifetimes. On the moon the corona will always be visible for 15 days at a time when the sun is above the horizon.

The wonders of the moon can be surmised from the earth, but to appreciate fully what one can see, one must go "out of this world." Through March and April visitors to the planetarium will have the opportunity to do so.

THE FRANKLIN INSTITUTE LABORATORIES FOR RESEARCH AND DEVELOPMENT.

***Abstract of* Film Pressure Distribution in Grease-Lubricated Journal Bearings.**[1]—GUNTHER COHN[2] AND JESS W. OREN.[3] Measurements of the pressure developed in the load-carrying film of a grease-lubricated journal bearing show that grease can operate under hydrodynamic conditions. In a testing fixture, constructed for the purpose, the magnitude and distribution of that pressure is investigated using a No. 2 grade ball- and roller-bearing grease under conditions of copious feed. Fundamentally, the fixture consists of a test bearing and a drill press, the arbor of which drives the journal. The latter is movable in such a way that a gage connected to a single tap hole can measure the pressure at any point in the film. The lubricant is fed into the bearing through an axial channel and is separated from the gage fluid by a diaphragm.

Pressure traverses were obtained for one load, one clearance and one L/D ratio at three speeds, after tests with a comparable oil had established the validity of the fixture and provided



Circumferential pressure distribution in journal bearing.

a basis for comparison. The graphical analysis of the results establishes a grease dome similar to that of oil, but flatter and extending over a broader arc. The circumferential pressure distribution in the center of the bearing is shown in the accompanying figure. In the direction of rotation, both the oil and the grease curves rise slowly to a peak on the "off" side of the line of application of the load, then fall more rapidly. A series of tests in which speed was a parameter demonstrates that the main effect of speed is a shifting of both leading and trailing edge angles of the film. No change of position or magnitude of the pressure peak can be observed. Integrated check plots show a very good correlation with the applied load.

It is hoped that this fundamental study will stimulate scientific analysis so that in time it will be possible to predict the performance of grease-lubricated journal bearings.

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[1] Contributed by the Special Research Committee on Lubrication for presentation at the Annual Meeting, New York, N. Y., November 28–December 3, 1948, of The American Society of Mechanical Engineers and for publication in the *ASME Transactions*. Paper No. 48—A–31.

[2] Research Engineer, The Franklin Institute, Laboratories for Research and Development, Philadelphia, Pa. Jun. ASME.

[3] Research Engineer, Armstrong Cork Company, Lancaster, Pa. Jun. ASME.

LIBRARY NOTES.

The Committee on Library desires to add to the collections any technical works that members would wish to contribute. Contributions will be gratefully acknowledged and placed in the library. Duplicates received will be transferred to other libraries as gifts of the donor.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. The average cost for a print 9 × 14 inches is thirty-five cents.

The Library and reading room are open on Mondays, Tuesdays, Fridays, and Saturdays from 9 A.M. until 5 P.M., and Wednesdays and Thursdays from 2 P.M. until 10 P.M.

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BOOK REVIEWS.

RADIO ENGINEERING, by E. K. Sandeman. 775 pages, 14 × 23 cm., plates, tables and drawings. New York, John Wiley & Sons, Inc., 1948. Price, $6.50.

Beginners in the field of radio engineering, maintenance personnel of radio stations, and amateur radio operators may find great interest in this first of two volumes devoted to working principles and practical applications of the technology of commercial transmitting station operation. While originally written as instruction material for maintenance engineers at the British Broadcasting Company, the scope was later widened to include more practical problems to make the resulting text somewhat of a book of reference for others experienced in the field. Since it is the aim of the work to provide a maximum of useful practical information with a minimum of effort on the part of the reader, the degree of mathematical maturity required is quite low, a working knowledge of elementary algebra and logarithms is sufficient for the "on the surface" understanding of the subject matter. Simple trigonometry is stated when necessary, and the first principles of complex algebra as are required for the manipulation of complex numbers in electric circuits are developed.

Of the sixteen chapters in this book, eight are devoted to: fundamentsls of electric circuits including discussions of units; the laws of electricity and electrical physics; alternating currents and voltages; resonance; power; and harmonic analysis and distortion. This material consumes approximately one third of the book. The remainder of the text considers the more advanced problems in station operation concerned with amplifiers, oscillators, modulators and

antennas and their coupling circuits. While entirely descriptive in nature, the subject matter is in many respects new, that is, has not appeared previously in textbooks.

Typical of this new material are the following subjects: practical methods of lining up Class C and modulated amplifiers and transmitters; operation of multivibrators; rapid methods for the design of coupling, filter, and equalizer circuits; antenna tuning for broadcasting stations and the design and operation of test instruments useful in transmitter operation. Throughout the book examples are worked out to illustrate the basic factual data, which allows the reader to quickly familiarize himself with the order of magnitude of the physical quantities involved.

The author tries to present, through a fundamental treatment, facts of observation, in many cases with no proof, with the underlying premise that if the principles are understood and properly used, then that is all that should be of concern. This reviewer is of the opinion that in an attempt to simplify so complex a subject as that of the practical aspects of radio transmitting operations and engineering, the author himself has perhaps been so carried away by his subject that there has been a certain amount of digression from the type of engineering preciseness so necessary in the statement and formulation of basic physical laws. While looseness of terminology and of fundamental definitions would not be bothersome to a beginner, there is danger that any misconceptions which may arise are carried on without future change. In spite of these pedagogical comments, the author has written a book which includes fairly complete instructions regarding the operation and the equipment encountered in carrying out the functions of a broadcasting station.

S. CHARP.

PRINCIPLES OF STEREOSCOPY, by Herbert C. McKay. 191 pages, 15 × 24 cm., drawings and illustrations. Boston, American Photographic Publishing Co., 1948. Price, $5.00.

Stereoscopic photography is the only known medium for reproducing a scene in three dimensions where all the objects are produced in their full natural size and at their full natural distance. This is done regardless of their size in the print. With the addition of color, motion, and sound to the picture, it is practically impossible to distinguish the photo from the original scene. Every amateur can turn back the clock or travel great distances in the wink of an eye.

A stereogram consists of nothing more than two ordinary pictures made of the same subject but from two positions separated laterally by the distance between a person's eyes. These pictures are mounted side by side and then viewed through a simple lens system called a stereoscope.

This fascinating hobby is one that every photographer can enjoy. As he takes it up, he will be like the "flatlander" who visits a three dimensional world. New and amazing vistas will be opened up to him. And when he has learned to make conventional stereograms, he can go on to some of the trick and puzzle processes. He can select persons well known to his friends, and by controlling the parallax, he can picture one of them full size beside the other who looks to be only a foot high.

The pseudoscopic stereogram is unique. The two pictures are transposed. Then objects near at hand in the original scene appear in the distance, and far objects are brought close. This inversion emphasizes the space relationships between the objects and presents an entirely new viewpoint. Irridescent slides may be hand drawn black and white lines. When viewed through the stereoscope, the mingling of black and white produces a scintillating effect.

Apparent motion can be imparted to still pictures of some subject such as a waterfall by making one view in bright light and the other in a dull light. "Then, due to retinal rivalry, the sparkling image will conflict with the dull one and often the effect is of moving water."

Stereo cryptograms can be made on a typewriter by controlling the spacing of the letters in a message. Selected letters in a perfectly straightforward and innocent text are moved very slightly to one side. Then when a duplicate of the letter is typed in the conventional way and the two letters placed in the stereoscope, the misaligned letters will stand out in stereo relief. Thus the secret message may be read. The amount of misalignment need not be large

enough to be detected by the unaided eye. These are some of the experiments that are explained in the text.

The book has detailed but interesting descriptions of the materials, processes, and equipment required to make all kinds of stereographs. The author explains how to make a simple sliding base which allows any camera to be used for making stereograms. The construction of other equipment is included.

In writing this book, the author has drawn on his considerable personal experience, the knowledge of other experts in the field, and his first hand knowledge of the difficulties of amateurs. The procedures to be used in taking, developing, printing, and viewing the stereogram are explained, and the difficulties and pitfalls to be avoided are pointed out.

Since many people who will try stereoscopy are already well acquainted and even steeped in the techniques of plane or two dimensional photography, some readjustment of their viewpoint will be necessary. Composition and lighting allow a photographer to take unattractive or even ugly objects and form a beautiful two-dimensional picture. But a pictorial stereograph must be made from a pictorial subject and cannot be obtained by using the tricks of plane photography. While a stereographer must be content to present existing beauty, there is no limit to the subject matter.

Some beneficial results may be obtained by viewing stereographs. Vision can be improved by one half hour of exercise daily. A stereoscopic view relaxes the eye muscles and allows the person to look into the distance. This is especially beneficial to the person who spends most of his time indoors. Special stereographs are often used by oculists to make eye measurements.

There are still many advances to be made in this 100 year old science. The basic principles are laid down but new techniques need to be developed. This is the challenge offered to amateur and professional alike.

The theories in this book will be interesting to the optical student and psychologist studying optical phenomena. But the text is of particular interest to both amateur and professional photographers, and it would make a wonderful gift for them. It presents some well known facts from a new view point and makes the plane photographer stop and examine his work and his techniques.

E. A. MECHLER.

MICROWAVES AND RADAR ELECTRONICS, by Ernest C. Pollard and Julian M. Sturtevant. 426 pages, 14 × 22 cm., drawings and tables. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd.; 1948. Price, $5.00.

The purpose of this postwar book dealing with postwar problems in microwaves and radar electronics is the presentation in compact form of the new techniques and manners of thought which have been found so useful in these fields. Based almost wholely on radar experience gained at the M.I.T. Radiation Laboratory, the authors have attempted to present a survey broad enough to give a general view of the field and a background on which the more serious reader can base further intensive study. In a style which is partly explanatory and partly descriptive, the authors have succeeded in reducing to some four hundred pages some of the material extensively covered in the now famous Radiation Laboratory Series.

The authors' fields of endeavor are physics and chemistry. It is not at all surprising that this book should pay special attention to the application of microwave techniques to these scientific fields, a comparatively new area for the use of cathode ray tube indicators, microwave cavities and wave guides, pulsed circuits and counters, and the many other electrical engineering off-shoots of radar engineering.

The thirteen chapters deal largely with technique and fundamental circuits which can be built up and experimented with in a physical laboratory. The essential facts of microwave circuits are developed after a consideration of the basic laws of electromagnetic fields, energy relations of the field, and plane waves and their reflections. The microwave fields described by the field laws are then considered as radiation fields confined in cavities and wave guides and coaxial lines. Cut-off relationships are developed and a brief but quite clear discussion is

given of the means of designating the various modes of TE and TM oscillations. In the sections devoted to the production of microwaves, there are found clear expository accounts of the operation of the klystron and the magnetron, with sections devoted to the experimental equipment necessary to plot performance charts and the Rieke diagram, which indicates how the composite system of magnetron plus variable line impedance behaves. There then follow in order unified sections devoted to: microwave techniques; pulse circuits; indicators; amplifiers; radar and microwave communications; and the use of microwaves in physical research.

Many circuits and sketches help the reader to understand the text material. Most of these used for illustrative purposes have component values marked on the wiring diagram, making it easy for the student to reproduce the sample circuits in the laboratory. As an additional aid in study, summarizing paragraphs and problems are included at the end of many of the chapters.

For readers who have not had an opportunity to participate in any of the developments described, this book affords a concise opportunity to appreciate the tremendous wartime development, for much of the subject matter was in the nature of laboratory curiosities eight years ago. While it does not seem to this reviewer that the book has sufficient intensive scope to serve as a textbook in a course for electrical engineers, the present day student in physics or chemical engineering can profitably read this book, especially since the text requires but a modest knowledge of higher mathematics. It could, however, serve as a reference and auxiliary text, especially for laboratory applications and techniques, for students in electrical engineering.

S. CHARP.

COMBUSTION ENGINES, by Arthur P. Fraas. 439 pages, 15 × 23 cm., tables, drawings, illustrations and plates. New York, McGraw-Hill Book Co., Inc., 1948. Price, $5.50.

The term *combustion engines* is taken to include only the commercially important types of heat engine, in which the working fluid consists of the products of the combustion of hydrocarbons and air, rather than steam or other vapor. This book is concerned primarily with reciprocating engines, but since the problems of combustion, practical thermodynamic analysis, fuel metering and injection, lubrication, etc., are so similar in gas turbines, it has proved to be quite simple to cover almost simultaneously most of the thermal and mechanical problems of gas turbines. Since the aerodynamics of gas turbines is a subject in itself, it could not properly be included.

The text has been designed primarily for the use of engineering college seniors and young engineers in the industry. Idealized relationships are developed from elementary theory, and practical application of these relationships to actual methods that have proved very satisfactory are then shown. In order to avoid obscuring relations of practical importance, most of the items and investigations carried out in the combustion-engine field that are largely of academic interest only have been purposely omitted. Charts and tables, useful in engine performance analysis, laboratory testing or development work are included, In addition, numerous illustrations have been selected carefully so that they are representative of engines of good design and can be used for a rather wide variety of performance estimations and design-analysis work.

S. M. BERKOWITZ.

PROTEIN AND AMINO ACIDS IN NUTRITION, edited by Melville Sahyun. 566 pages, 16 × 23 cm., tables, drawings and illustrations. New York, Reinhold Publishing Corp., 1948. Price, $7.50.

Researchers in the fields of medical science and nutrition should find great professional delight in reading this book concerned with certain special aspects of food, especially the role of protein in nutrition, in the broadest use of this word. Written by eighteen contributing authors, the work is a compendium of information collected from the point of view of these research personnel who in their everyday work as investigators are concerned with the intelligent use of food in health and disease.

As a source book and a guide to the literature in the specialized field of protein research in nutrition, the book is, no doubt, one of the few of its kind available; more than two thousand publications are listed as references at the ends of the separate chapters, some dating as far back as the first half of the eighteenth century up to the present time.

As used in the title of this volume, the word nutrition refers not only to the consequences of using proteins and the amino acids as elements of food for the normal body functions, but there is also great interest in the use of these compounds in pediatrics, pregnancy, surgery, metabolism, and burns. Also considered is the effect of protein deficiency, which is examined in its relationship to nutritional anemia and resistance to infection.

An introductory chapter provides valuable historical orientation regarding the part played by protein chemistry from an early age. The major developments by scientists in Europe and the United States are briefly described and their findings are tied together to form a running account of active research developments which led to new discoveries, each new one acting as a stimulus for further developments in the science.

Successive chapters deal with the application of nutritional principles to the practical problems of feeding, and the salient factors influencing the caloric, vitamin, and mineral requirements of the body. Much of this necessary information is to be found in some of the most comprehensive tables available on the composition of natural and processed foods, included for the first time in this book. The protein nature of toxins and antitoxins is examined as is the protein nature of filterable viruses.

On reading this excellent book, it becomes apparent that we are living in a period of high dietary protein, emphasized by the amount of research in this particular field of medical science.

While the fifteen chapters were written by a number of authors, the general editing has resulted in a readable book. The highly technical nature of the volume should appeal to research persons in this field, physicians, students in the medical science, and others who should be well informed in the latest developments with reference to proteins.

S. CHARP.

ADVANCED DYNAMICS, by S. Timoshenko and D. H. Young. 400 pages, 15 × 23 cm., tables and drawings. New York, McGraw-Hill Book Co., Inc., 1948. Price, $5.50.

This book is not particularly advanced in the sense that it deals with the more complicated problems encountered in dynamics. But it is really advanced in the detailed treatment of each of the phases of dynamics in that it takes the simple, basic laws and from them derives the necessary algebraic solutions, shows methods of integrating differential equations by numerical and graphical methods, and suggests procedures that are useful for many other similar problems that the engineer or student will encounter in his daily work. Valuable space is not wasted on unnecessary proofs of physical laws, but the reader is led as directly as possible to the desired result, often by such a course as to indicate points at which deviations can be made for computing other groups of problems of a similar nature. Many examples and typical problems are given that suggest solutions for more advanced ones in which the research engineer will undoubtedly be interested and in which he should be able to use the methods suggested herein to excellent advantage.

The increased use of high-speed machines and super-sonic flight have drawn the attention of engineers and scientists to the unusual dynamic problems encountered in their engineering and design studies. They find it necessary to analyze the rectilinear motion of machines under various conditions of constraint and determine their vibratory characteristics. This book presents the general principles of dynamics and demonstrates their application to most of these modern problems.

The book is divided into five chapters treating various phases of dynamics in a logical manner. The first chapter deals with the dynamics of a particle and the solution of the differential equation of motion for any conditions likely to be encountered by practicing engineers. A section of this chapter develops the mathematics of rectilinear motion with various kinds of resistance, several sections explain the types of vibration likely to be encountered, one section is on planetary motion and one on exterior ballistics. Methods of graphical and

numerical integration are shown that are useful in the solution of differential equations of motion.

In the second chapter, the dynamics of a system of particles is developed for linear and angular momentum. The law of conservation of energy is developed from basic equations of work and applications given.

The third chapter discusses the dynamics of systems with constraints and introduces the notions of generalized coordinates and generalized forces. The use of D'Alembert's principle in conjunction with the principle of virtual displacement is given as a general method of solving problems involving systems with contraints. The Lagrangian equations of motion and Hamilton's principle are discussed.

Small vibrations of conservative systems having free and forced vibrations with two degrees of freedom are discussed in the fourth chapter. Using the Lagrangian method of writing the equations of motion, systems are treated for several degrees of freedom and for an infinite number of degrees.

The last chapter treats of the rotation of a rigid body about a fixed point and the development of Euler's equations of motion in this connection. The theory of the gyroscope is also presented together with various practical applications.

Each chapter is complete in itself and covers sufficient material that one or two of these chapters can be made the subject of a course as an instructor may select.

F. R. SIMPSON.

PRINCIPLES OF PHYSICS III OPTICS, by Francis Weston Sears. 369 pages, 15 × 23 cm., drawings and illustrations. Massachusetts, Addison-Wesley Press, Inc., 1948. Price, $4.50.

This third volume of the author's series of physics text books was written primarily for use as the concluding work in a two-year course in general physics offered to students in one of this country's great engineering schools. As such, it is naturally concerned with presenting the principles of geometrical and physical optics with emphasis on engineering application. The unified treatment of the text material is no doubt the result of ten years' usage of previous editions, as well as its intensive classroom use. Within the confines of this single volume has been accumulated a wealth of mathematical material pertinent to the field of optics, couched in the language of the physicist and the engineer.

After an introductory chapter on the nature and propagation of light, the book considers in turn the problems of reflection and refraction at plane and spherical surfaces and lens. Illustrated copiously with the usual line diagrams and in some cases with white on black drawings, these chapters develope the fundamental relationships of geometrical optics, such as: Snell's law, Fermat's principle of least time, and laws for thin and thick lenses. An entire chapter is devoted to aberrations, with discussions and illustrations of spherical and chromatic aberration, coma effects, correctors such as those invented by Schmidt and Makutsov, astigmatism and curvature of field and distortion. The student is shown the basic design methods for lens and mirrors combinations to correct for many of these inherent departures of the actual image from the predictions of first order theory. As a fitting conclusion to the section on geometrical optics there is included a chapter on the more common optical instruments, such as: spectacles, telescopes, cameras, rangefinders, and the prism spectrometer.

In this third edition, the second half of the work, concerned with physical optics, has been largely rewritten. Here the wave nature of light plays an important part, as is manifest in the discussions pertaining to polarization, interference, diffraction, and the limit of resolution. Linearly and elliptically polarized light is investigated for its reflection and refraction characteristics when passing through: single and multiple plates and crystals, analyzers such as polaroid discs, and retardation plates. Interference phenomena of the electromagnetic waves are studied primarily by examples such as: Newton's rings, the Michelson interferometer, plane and concave gratings, and Fresnel zones. Considerations of emission from light sources, line spectra, photometry, and color form the subject matter of the remainder of the book.

The author has covered each of the topics in a style which makes for easy reading and

study. Numerous examples intersperse the text material and help clarify many questions which may arise, especially with regard to order of magnitude of the optical effects considered. Well-chosen problems appear at the end of most of the chapters with the answers to many of them included in the book. While principally an undergraduate text book, this volume can very well serve as a basic reference book for practicing engineers who occasionally meet with optical problems in equipment design.

S. CHARP.

INTRODUCTION TO ENGINEERING PROBLEMS, by Robert Q. Brown. 191 pages, 14 × 22 cm., drawings. New York, Prentice-Hall, Inc., 1948. Price, $2.95.

This book is written as a text for a basic freshman engineering course in engineering problems. To quote from the author's foreword, "Engineering Problems should have as their prime purpose the early training of all engineering students in good habits of work and study and the establishment of a closer bond between the contents of courses in mathematics, physics, and applied mechanics by drawing on engineering settings for problems, in order to permit students who have no aptitude for engineering to discover that fact early in their college careers and go into more congenial lines with the minimum loss of time."

The text appears to fulfill the requirements established in the foreword. The principles set forth are well illustrated with numerous examples. In addition, there are almost 200 problems for the student to work out. The problems are well chosen as illustrative of the material presented in the text, and are typical of the elementary type of engineering problem encountered by the graduate. The last section of the book is devoted to four engineering projects which will give the student an idea of the more comprehensive scope of engineering problems he will eventually encounter in his chosen field. The successful completion of these projects requires not only a knowledge of physical and mathematical principles, but also the exercise of sound judgment and evaluation.

In addition to covering the more basic principles of physics and mathematics, the book devotes an entire section to "Good Form in Writing." This section also contains a large bibliography for further reference on the subject. Incidentally, the introductory section, "The Objectives of Engineering Problems," also contains an excellent bibliography of articles and books designed to give the starting engineering student an understanding of what the future may hold for him and what is expected of him as an engineer.

"Introduction to Engineering Problems" is a book which will be saved by the student as a valuable reference book after it has served its initial purpose of introducing him to the subject of engineering problems.

R. S. GRUBMEYER.

GAS TABLES, THERMODYNAMIC PROPERTIES OF AIR PRODUCTS OF COMBUSTION AND COMPONENT GASES, by Joseph H. Keenan and Joseph Kaye. 238 pages, 19 × 26 cm., tables. New York, John Wiley & Sons, Inc., 1948. Price, $5.00.

This book supersedes the previous efforts of Professors Keenan and Kaye, "Thermodynamic Properties of Air." For compilation of Gas Tables the properties of air were re-examined and recalculated, and tables of functions useful in the analysis of the flow of compressible fluids were extended.

Additional data include Tables 30 to 53 reprinted from Meteor Report 14, entitled "The Mechanics and Thermodynamics of Steady One-Dimensional Gas Flow with Tables for Numerical Solutions," by A. H. Shapiro, W. R. Hawthorne, and G. M. Edelman; and Tables 55 to 59 reprinted from Bumblebee Report 26, entitled "The Theory and Practice of Two-Dimensional Supersonic Pressure Calculations," by N. Edmonson, F. D. Murnaghan, and R. M. Snow. Although the major tables of thermodynamic properties can be used in the analysis of the flow of compressible fluids, these excellent tabulations were included because of their greater specific convenience.

Since dependable values of viscosity and thermal conductivity for air cover a limited range of temperature—for other gases an entirely inadequate range—values of these properties were

tabulated only for air in Gas Tables. Correlation of existing data and some measurements to obtain new data are in progress for other gases; and as the results of this work become available they will be incorporated into Gas Tables, according to Professors Keenan and Kaye.

Other additional data included in Gas Tables are the properties of combustion products of hydrocarbons and of the constituent gases.

All values of thermodynamic properties in Gas Tables are based on the examination of data from spectroscopic sources which were published in 1945 by F. D. Rossini and his coworkers at the National Bureau of Standards.

The base temperature, for which enthalpy is zero, is not the same in Gas Tables as in Thermodynamic Properties of Air. It is taken to be zero on the absolute Fahrenheit scale in accordance with Rossini's data. Negative values of properties are thereby avoided. The molal unit is employed for all tables of thermodynamic properties except air, and as compared with the mass unit, the molal unit makes the range of values between tables very much smaller. It also permits the use of a single table for the products of combustion corresponding to a wide range of carbon-hydrogen ratios, provided only that the "percentage of theoretical air" is held fixed. Certain other interpretations of the same table in terms of mixtures of air and fuel vapor and of air and water vapor are also valid to good precision.

For engineering application to the design of power apparatus, the precision of Gas Tables is of the same order as that of modern steam tables, but the convenience is of a higher order.

Sources and methods, and examples in application of the tables are included.

MAX W. BERG.

PHOTOGRAPHIC EMULSION TECHNIQUE, by T. Thorne Baker. Second edition, 336 pages, 14 × 20 cm., tables, drawings, and illustrations. Boston, American Photographic Publishing Co., 1948. Price, $7.50.

This new edition of the author's earlier work generally follows the same pattern as the first edition in format and chapter headings, with a few changes in subtitles and two new chapter headings, one on three-layer color films, and one on testing emulsioned products. Throughout the book the author has revised the text to bring it up-to-date with the best information about emulsions which the manufacturers will divulge.

In his introduction he points out that for years there were many closely guarded secrets in the manufacture of photographic emulsions, and that the only way to learn emulsion-making formulas and technique, until fairly recently, was to be associated in the actual manufacture of films, which has been the author's experience for thirty years.

Beginning about 1923, with the disclosure by Dr. S. E. Shephard, of the sensitizing effect of allyl isothiocyanate, more and more "secrets" were disclosed. (An apochryphal story has it that a buyer of hides for one of the large film companies knew this empirically for many years and always purchased hides from steers slaughtered in the spring when wild mustard was in bloom. Hides from these animals contained allyl mustard oil or allyl thiocyanate, and emulsions made with gelatine derived from these hides were faster than emulsions made with gelatine derived from other sources.)

Following Shephard's disclosure, articles were published in many scientific journals by the scientists engaged in research on the subject of emulsions. Mr. Baker has gathered together in one volume the theories and also the practical formulas and technique of making emulsions in small batches for experimental purposes in the belief that there are certain phases of research which require emulsions different from the regular runs which manufacturers turn out for the trade, and that the only way a research laboratory can get them is to make them.

Chapter references are included in a table at the end of the book as well as an author index and a subject index.

GLADYS MÜLLER.

EVALUATION OF RESIDUAL STRESS, by K. Heindlhofer. 196 pages, 14 × 21 cm., drawings, tables and illustrations. New York, McGraw-Hill Book Co., Inc., 1948. Price, $4.00.

The evaluation of the intensity and distribution of residual stress in metallic structures is of extreme interest to manufacturers, engineers, and metallurgists. But there has been little

written in book form on the nature, detection, measurement and analysis of residual stress. Now in a comprehensive treatment of this ever increasingly important subject, the well qualified author has written a short but relatively detailed and practical book which can serve as a text for graduate students in mechanical engineering and metallurgy, and at the same time it can be used as a reference by the practicing engineer who is confronted by certain stress problems.

Residual stress is that stress which would exist in an elastic solid body if all the external load, acceleration, and gravitation were removed. Fabricators meet with examples of the effects of residual stress as daily occurrences, since they may be induced in the course of the manufacturing process, in castings, welds, and the rolling and joining of metal sheets. Once present, residual stress manifests itself in mechanical and/or chemical effects, such as warping or cracking of quenched high-carbon steel articles, changes in dimensions during machining, and grain-boundary corrosion which may result in loss of cohesion at the boundaries, resulting finally in complete rupture.

In some cases, residual stress may be turned into an asset, but to do so requires a basic knowledge of stress and strain relationships, and a good acquaintanceship with the various means for the detection and measurement of residual stress. This book attempts to clarify these points.

A first expository chapter is concerned with the nature and significance of residual stress, laying down the mechanical sources of this stress with an explanation of possible consequences when residual stress is present. The nature of metal itself, as a crystal, with its anisotropic properties, is next considered, as are the effects on stress analysis of non-homogeneity and crystalline metal texture. Having thus introduced the subject, the pertinent phases of displacement, starting with the derivation of certain basic formulas restricted to homogeneous strain, a quantitative treatment of strain and stress and their interrelation, shear and various shear diagrams are considered. The case of stress in the vicinity of a point, based upon geometrical relationships, is studied as well as the relation of strain to stress for an isotropic body, which is based on experiments pertaining to the elastic behavior of certain materials such as metals. The impossibility of calculating stresses within a self-stressed body from observations restricted to the surface measurement of strains is discussed.

Two chapters are devoted to the various methods of observation and the necessary instruments and circuits. Sectioning, machining, etching, and stress relief are discussed, especially in their relation to means of measurement by usable gauges which are based upon the following physical effects: elastic change in spacing between atomic planes, change in macroscopic spacing, or the change in electric resistance caused by elastic strain in a wire.

In this book fundamental ideas of stress and strain, internal and external, are fully explained from the viewpoint of the physicist and metallurgist. It should be of great interest to the other branches of engineering as a reference guide in this field.

S. CHARP.

PRINCIPLES OF RADAR, by Denis Taylor and C. H. Westcott. 141 pages, 15 × 22 cm., plates, drawings and tables. New York, The Macmillan Co.; Cambridge, The University Press; 1948. Price, $3.50.

This book is one of a new British series called "Modern Radio Technique" which deals with the advances in radio technique made during the war. It is intended as an exposition and survey of the principles underlying radar design. The authors predicate the book with a hope that "it will be of service to readers who have found the sudden release of so much detailed information to lead to mental indigestion, by indicating common factors which underlie the many types of radar equipment which have been developed and used during the war."

Dr. Taylor is a Superintendent at the Telecommunications Research Establishment of The Ministry of Supply, and Dr. Westcott is now with the Physics Department at Birmingham University.

To those engineers, physicists, and mathematicians who have been associated with radar techniques during the war years, this book will be attractive because of its clear presentation

of the fundamental concepts. And to those scientists who are unfamiliar with these techniques, the book offers an illuminating introduction to this tremendously important field. The only prerequisites for a thorough understanding of the material presented is a knowledge of electromagnetic theory, the calculus, and the $j(=\sqrt{-1})$ convention, as well as some acquaintance with normal radio practice.

The first eight chapters of the book are devoted to an exposition of the principles of radar, excluding those cases where a responder (beacon) is placed in the target to be located. In this portion of the book the authors present an excellent description of the generation and reception of coded pulses, radar performance characteristics, methods of getting range, azimuth and elevation by radar, and also the unwanted echo problem. Included in the text are many numerical examples to illustrate the application of the relationships developed. The authors make no attempt to complicate matters by introducing any circuit theory.

The uses and principles of responders are dealt with briefly in Chapter 10. Chapter 9 gives a summary of the characteristics of a selection of typical practical radars, correlating the particular applications of the principles mentioned in the earlier chapters, and also illustrating how such factors as the choice of wave-length work out in practice.

Practicing radar engineers will find this book to be of great value, although it is primarily intended for those scientists who are not actively engaged in this field but are sufficiently interested in becoming enlightened on this fascinating subject.

D. M. BIBERMAN.

CATHODE RAY TUBE DISPLAYS, edited by Theodore Soller and others. 746 pages, 16 × 23 cm., tables, drawings and illustrations. New York, McGraw-Hill Book Co., Inc., 1948. Price, $10.00.

This book is Volume 22 of the Radiation Laboratory Series and is published with the approval of the Office of Scientific Research and Development. Like the other books in the series, it contains a wealth of information and descriptions of new techniques discovered on war time radar development projects. As the name implies, this volume deals with cathode ray tubes and the circuit techniques involved in their use.

The emphasis is on the use of cathode ray tubes for radar displays and precision laboratory instruments. Television applications are mentioned but not stressed. But so much basic cathode ray tube theory and so many basic circuit design principles are included in this book, that it is a highly desirable reference. It should be on the required list for every technical library in the country, whether independent or associated with industry or educational institutions.

The information on cathode ray tubes is detailed. The different types of tubes, construction, phosphors, spot size, deflection, and theory of operation are discussed. And this information is valuable to any engineer who requires more than a superficial knowledge of cathode ray tubes.

Some of the information found in this volume is also contained in other volumes of the Radiation Laboratory Series to make them more coherent. Likewise this volume can stand by itself. It contains enough information on general radar theory so that the reader can understand the special requirements for the various cathode ray tube displays. The text is a desirable possession for any electronic engineer and is essential for the designer of cathode ray tube displays.

A good deal of emphasis is placed on the limitations and possibilities of the "scope" as a medium for displaying information. But to realize the most from a tube requires the knowledge of circuit techniques and optical systems that are also presented. Many clever and interesting devices were developed during the war. To put reference information on the offset PPI scopes, photoelectric circuits are used to generate angle indices. Photographic projection systems that use high speed developing and fixing are discussed, and information on dark trace screens is included. The many schematic circuits for the test equipment and display systems included in the text show the values of nearly all the circuit parameters.

It should be borne in mind by the reader that the basic principles for designing cathode ray tube displays are laid down in this book. But these principles have been used since the war to refine and improve the circuit techniques beyond what is published here and elsewhere. With the knowledge offered by this text, the engineer is in a position to improve on the basic designs illustrated in the book and to design displays to meet his own particular requirements.

E. A. MECHLER.

CHEMISTRY AND USES OF INSECTICIDES, by E. R. De Ong. 345 pages, 14 × 22 cm., illustrations. New York, Reinhold Publishing Corp., 1948. Price, $6.00.

The field of insecticides considered in this book is not that of the scientific or chemical study of these preparations; it is rather the field of insecticides which is of primary interest to the public as a whole. As such it is concerned with an exposition of the intelligent use of certain chemicals for very practical purposes, especially agricultural.

The development of specialists in the control of insects on growing crops by chemical application, dating back to about 1860, has progressed to the point where two related groups are now intimately concerned with this general problem: economic entomologists who have a basic knowledge of insects and related forms; and plant pathologists, who specialize in the fungi and bacteria which attack plants. These groups have developed the terms insecticides and fungicides, with a further breakdown of the former into: stomach poisons; contact sprays; and fumigants. The terms are self-explanatory. Since many chemicals fall into two or even all three of these categories, there is a recent tendency to classify insecticides in accordance with their field of application, such as agricultural insecticides and fungicides and household insecticides.

For the most part, the early developed insecticides were inorganic chemicals, such as arsenic, lead, calcium, barium and mercury, with copper and sulfur being the principal fungicides. Toward the turn of the century it was realized that arsenic is a protoplasmic poison, and effort was devoted to the development of organic materials, starting with pyrethrum flowers and nicotine, and continuing into the present with such developments as DDT, naphthalene derivatives, organic mercury and sulfur compounds, and others.

The book is written in catalogue fashion. By this is meant that the material is systematically arranged with separate chapters devoted to: arsenic, copper, and sulfur and their compounds; minerals and oils; fumigants and fumigation; plant derivatives; synthetic organic compounds; and heat, cold, and radiation as insecticides. Each chapter devoted to these insecticides includes information regarding its chemical nature; its effectiveness on various types of insects; cautions regarding its use; methods of application to crops, and other pertinent data. While the book may be of interest to the general scientific reader, it is especially designed to meet the need for a general and comprehensive treatment of insecticidal materials and their agricultural applications as may be encountered by insecticide manufacturers, botanists, entomologists, agricultural research workers, farmers and even those homeowners who are amateur gardeners. Written in a systematic and most thorough manner, from the practical point of view, the book can be well adapted for use as a text book in agricultural colleges, for it considers as subjects of secondary interest problems of supply, labeling, packaging, antidotes, and the mechanical problems of grinding, formulation, and application. The many insecticides considered are listed in catalogue fashion, making the work of further interest to the professional worker who must be kept abreast of all the new and promising compositions as well as those which are well established. Readers who are laymen and manufacturers in this field will find great interest in the indices which include: a chemical and common name glossary; official antidotes for the common poisons; legal requirements for manufacture; and other miscellaneous chemical and physical data.

S. CHARP.

MICHIGAN AND THE CLEVELAND ERA, edited by Earl D. Babst and Lewis G. Vander Velde. 372 pages, 15 × 24 cm., Port. Ann Arbor, The University of Michigan Press, 1948. Price, $2.50.

There are several paths of approach to the problem of judging the value of a university's contribution to the community. At Michigan University there is evidently a high appreciation of a university's fundamental objective, for it is assumed to be the training of its students to become useful members of an integrated society. Which, after all has been said, is just about as high an ideal as any university may set itself.

This volume sets forth the record of achievement by graduates and faculty members of the University of Michigan during a turning point in national history as proof that the high ideal has been attained. The period chosen covers the years of the Cleveland administration. Although he had no direct ties with the university, President Cleveland had as adviser an alumnus of distinction in the person of Don M. Dickinson, who became chairman of the Democratic National Committee and who served as Postmaster General in the first Cleveland administration. Largely as a result of the latter's control of patronage and his influence over the making of appointments, an unusually high percentage of Michigan graduates and faculty members were called to fill a variety of official positions. How ably they discharged their duties is set forth in a series of well written chapters of biography dealing with those who filled the major posts. Additional chapters treat with the alumni who gained seats in Congress and in the judiciary.

Issued by the Michigan Historical Collections of the University of Michigan, this book should be a source of pride to graduates and an informative guide to those who seek evidence that American higher education justifies the effort which has gone into its establishment and continued support.

T. C.

SCIENCE AT WAR, by J. G. Crowther and R. Whiddington. 185 pages, 14 × 22 cm., drawings and illustrations. New York, Philosophical Library, 1948. Price, $6.00.

The title of this book is descriptive of the subject matter, except to say that the book is written from the British point of view and is largely limited to British scientific contributions to the winning of World War II. To those of us who have read and heard so much about American scientific achievements, the British viewpoint is refreshing in addition to being highly interesting.

Almost half of the book is devoted to radar, the field in which the British apparently made their greatest strides, and the tool which many believe saved England from a German victory. The full story of radar development is traced here, with a balance between the tactical necessity for the succeeding steps in radar development and the technical evolution of the resulting radar systems.

The remainder of the book is devoted to sections entitled "Operational Research," "The Atomic Bomb," and "Science and the Sea."

The section "Operational Research" describes the scientific research done in the field under actual operating conditions. The British realized early in the war that a need existed for close coordination of laboratory development and tactical, strategic, and operational requirements. To obtain information on field conditions, they placed many scientists in the field with troops and equipment. The advances resulting from this practice are fully described.

The section "The Atomic Bomb" is mostly physical and historical background material for the development of the bomb. The part played by British scientists in the development of nuclear theory is thoroughly dealt with.

The section "Science and the Sea" describes developments in underwater sounding, depth charges, mine sweeping, etc.

The book is written in semi-technical language, and the story is told in a way which will make it understandable to the layman without insulting the intelligence of the trained scientist. The text is greatly helped by the large number of illustrations and photographs.

R. S. GRUBMEYER.

AMERICAN PHOTOGRAPHIC ANNUAL OF PHOTOGRAPHY 1949, edited by Frank R. Fraprie and Franklin I. Jordan. 240 pages, 18 × 25 cm., illustrations and drawings. Boston, American Photographic Publishing Co., 1948. Price, $2.00 (paper).

The 1949 American Annual of Photograpahy follows the same general plan that has been used by this periodical for a great many years. There is the usual section of photographs selected from the annual crop of salon prints, somehow not as exciting as some of the pre-war numbers. It has always been a source of regret to this reviewer that the American Annual uses calendered paper for its reproductions of salon prints. Doubtless, rendering of the fine detail of the original is better acheived with a fine half-tone screen on calendered stock. Nevertheless, it is seldom as aesthetic a presentation of a pictorial subject as the softer and richer tones of a gravure print on a smooth matte surfaced paper, such as was used by some of the foreign annuals before the war, and since, in the case of the British Journal.

Among the articles, one by Yousuf Karsh describes his experiences in photographing famous musicians and singers whose portraits are included in the article, but neglects to give even a hint as to the technical background of how he made them—doubtless a "trade secret".

A technical article by T. Thorne Baker describes some of the characteristics of printing with the color-sensitive double-coated print emulsions such as Varigam, and one by Arthur W. Judge on the Importance of Definition in Stereoscopic Photography" gives rules for obtaining the desired result.

An article by Don D. Nibbilink on Samuel F. B. Morse should settle once and for all the long standing controversy over who took the first photograph in America.

In "Sharpness and Pictorialism," Eleanor Parke Custis writes an excellent plea for the soft-focus picture and defines her point with some of her very beautiful landscapes, outlining her reasons for allowing some details to blend and for permitting others to stand out sharp and clear. Her arguments have validity when considered with the pictures she uses for illustration of her point. Many pictorial workers could benefit by close attention to her thesis.

The article on "Plant Portraits," a subject which seems to delight the editors, since the monthly magazine, as well as the annual, usually includes at least one article on the subject, leaves this reviewer unmoved.

A brief article by Arthur Hammond on "Balancing the Negative," is interesting for its historical outline of the methods used by early workers in achieving balance by inspection but does not offer much help, except by inference, to the modern worker using fast films which must be developed in total darkness.

The lead article with illustrations is a memorial to the late British photographer Alexander Keighly, Hon. F.R.P.S. Planned by the author, J. Dudley Johnston, as a small book to commemorate Keighly's 50 years as a pictorial photographer, it was denied publication during his life-time because of the paper shortage in Britain. Many modern photographers will find the subject matter of his pictures and the technical treatment too much on the sentimental side to be wholly satisfying.

An article on the "Preservation of Daguerreotypes" by the editor, Frank R. Fraprie, and a description of the prints in the salon section, with data on how they were produced, also by the editor, help to bring this annual up to its customary size.

Outstanding prints in this issue include most of the prints in the article by Eleanor Parke Custis, the portraits of Marian Anderson and Artur Rubinstein by Yousuf Karsh, and in the pictorial section the portrait of Alfred Stieglitz by Georgia Engelhard, White Chimneys by L. H. Longwell, Splash! Splash! by Fred Bauer Jr., Inquisitor by B. Charles English.

GLADYS MÜLLER.

COBALT, by Roland S. Young. 181 pages, 15 × 24 cm., tables and illustrations. New York, Reinhold Publishing Corp., 1948. Price, $5.00.

Chemists and those in allied fields of science are familiar with the series of monographs published under the auspices of the American Chemical Society. This book, on the subject of the physical and chemical nature of the element cobalt, is the one hundred and eighth of the series. As with other monographs in the series, the volume serves two purposes: to make

available to chemists a thorough treatment of a selected area in form usable by persons in more or less unrelated fields; and to stimulate further research in the specific field treated. In addition, the monograph on cobalt is written for two classes of readers: the chemist or other scientific worker who requires accurate and up-to-date information; and the chemist or metallurgist who wishes simply to increase the scope of his knowledge in this field.

While much has been written regarding the chemistry and metallurgy of cobalt, for the most part this information has appeared as widely scattered papers in the technical literature. The author, who is actively engaged in the mining and purification of cobalt, not only has collected together sufficient material for a well written monograph, but he has also included in this publication material regarding certain unpublished features and developments which have come within his own experience.

A first chapter investigates the historical nature of cobalt. As early as the sixteenth century this element, while not isolated, was included in the alchemical literature of the period; it was not until about 1780 that the properties and elemental characteristics of the material were studied.

Cobalt is widely diffused in nature, there being approximately 0.001 per cent in the earth's crust. However, it almost never occurs in a pure form, the principal cobalt minerals being the sulfides, arsenides, sulfo-arsenides, and oxides. These minerals and their geographical distribution are described, with sketch maps showing the immediate regions surrounding the principal mines in Africa and Canada.

In processing the cobalt minerals, there is found an extremely wide diversification of metallurgical operations. A chapter is devoted to detailed descriptions of the current practices for extracting cobalt as followed in the principle refineries throughout the world. Following chapters discuss the important chemical, physical and mechanical properties of cobalt and its principle compounds.

The second third of the monograph is devoted to the use of the element: in ferrous and non-ferrous alloys; in powder metallurgy; in electroplating; and as a coloring agent in the glass and ceramics industry. The catalytic behavior of cobalt, its chemical and physical analysis, and certain biological and biochemical relationships are discussed in closing chapters.

The thirteen chapters devoted to the subject matter enumerated above, while somewhat sketchy in parts, are written with sufficient scope as to evince interest on the part of the reader to investigate certain problems in greater detail, especially with the assistance of the lengthy lists of references at the end of each chapter.

S. CHARP.

BOOK NOTES.

PETROLEUM PRODUCTION, by Park J. Jones. Volume 4, 238 pages, 15 × 23 cm., tables and drawings. New York, Reinhold Publishing Corp., 1948. Price, $5.00.

This fourth volume in the series by Mr. Jones on Petroleum Production considers the important subject on condensate production and cycling. In the first part he considers the fundamentals, treating of condensation in reservoirs, injection into rich gas, injection into water, production by expansion, displacement and expansion, and the economics of condensate production.

In the second part he considers applications to particular types of reservoirs—radial, elongated and linear. The final chapter discusses the maximum efficient rate of production as contrasted with the optimum rate of production.

THE CHEMISTRY OF THE POLYSACCHARIDES, by Robert J. McIlroy. 118 pages, 14 × 22 cm. New York, Longmans, Green & Co.; London, Edward Arnold & Co.; 1948. Price, $2.50.

For the use of teachers, honors students and research workers, the author has presented this compact resumé of the modern developments in the field of carbohydrate chemistry, particularly the polysaccharides. Because of the condensation of treatment, numerous references to the literature are given at the end of each chapter. The volume includes a

chapter devoted to the estimation of carbohydrate in biological material and also one on metabolism of both animals and plants.

MICROWAVE MAGNETRONS, edited by George B. Collins. 806 pages, illustrations, diagrams, 15 × 23 cm. New York, McGraw-Hill Book Co., Inc., 1948. Price, $9.00.

The magnetron is one of the important components in radar systems. Proceeding from the pulsed 10-cm. magnetron developed in 1940 by the British, this volume records most of what was known about microwave magnetrons as of January, 1946. The particular class of magnetron considered is "distinguished by a resonant system within the tube envelope."

After a brief historical review, the principal types of resonant systems used are described: the unstrapped resonant, the rising-sun and the strapped systems. The second part is devoted to an analysis of operation while the third takes up the design of a magnetron considering these four principal components: the cathode, the interaction space of the fields and electrons, the resonant system, and the magnetic circuit.

An important consideration in microwave magnetrons is tuning, and two methods, mechanical and electronic, are described in detail. Practical hints to be followed in building a magnetron are given in the final part. A chapter on "Typical Magnetrons" presents specific data on the main types of microwave magnetrons in the frequency range of 1000 to 24,000 Mc/sec. and output-power range of 25 watts to 2.5 mw. This comprehensive volume is number six in the Massachusetts Institute of Technology Radiation Laboratory Series.

NOTES FROM THE BIOCHEMICAL RESEARCH FOUNDATION.

***Abstract of* Nucleic Acid Content in Intestines of Rats after X-Radiation.**—J. O. ELY AND M. H. ROSS (*Cancer Research*, **8**: 285, 1948). The chemical changes which are produced in tissues by X-radiation, and which later result in morphological changes and clinical effects, are not well understood. Since nucleic acids apparently are fundamental constituents of all cells, changes in the cell content of these compounds offer a means of studying the effects of X-radiation.

This work is a continuation of studies of radiation effects previously reported.[1] The destructive action of X-radiation on cancer cells may result from changes produced in nucleic acids. If the mechanism of this action were explained it might be possible to produce similar results affecting only the cancer cells.

The high absorptive capacity of nucleic acids for ultraviolet light of 2,500 Å to 2,800 Å, with a maximum absorption at 2,600 Å, makes possible the determination of the location and amounts of these compounds in histological sections of tissues. The quartz optical system microscope, often called the ultraviolet microscope, in combination with a source of monochromatic light, is a useful instrument for studying the absorptive capacity of tissues for ultraviolet light. This instrument has been used in the present investigations to determine the effect of X-radiation on the amount of nucleic acids in tissues of the rat intestine. Use was made of the Feulgen reaction, ribonucleinase, methyl green-pyronin stain, and extraction of nucleic acids by hot trichloracetic acid to supplement the ultraviolet light absorption technic. The technic of micro-incineration was employed to study the effect of X-radiation on the amount of mineral constituents.

It was found that a comparatively small dose (600 r) of whole-body X-radiation produced decreased amounts of nucleic acids, mineral constituents, and structural proteins in the crypts of Lieberkühn in the intestines of rats.

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[1] BIOCHEMICAL RESEARCH FOUNDATION STAFF, "Neutron Effects on Animals," Baltimore, Williams and Wilkins Company (1947).

CURRENT TOPICS.

New Filing System Will Speed Search for Chemical Formulae (*Aminco Laboratory News*, November, 1948).—A new and simple tool for recording and finding information about simple or complex chemicals and their properties has been developed by Calvin N. Mooers of the Zator Co., Cambridge, Mass.

Already in use by one large pharmaceutical research laboratory for keeping track of its organic chemistry experimental work, the new application of the Zator method of indexing information promises to speed research by allowing exploration of related compounds that might be overlooked by the usual laborious complicated filing.

Simple codes are used for the essential parts of the structural formulae of the chemicals, and the use of complicated chemical names in indexing is abandoned. The new method actually puts as many as a dozen pieces of information on a simple notched card. Mechanically sorted according to the random pattern notches, it is easy to pick out any desired combinations of chemical or other properties.

When more widely used, this chemical zatocoding, as it is called, promises to bring to attention compounds for medical or other use that would otherwise be overlooked. It will now be possible to search for unexpected combinations of chemical structure and properties that research shows are desirable.

Untangling complex patent claims is another application of the new method. Each factor in the chemical structure is described on the card in a complete and direct fashion. The number of rings is noted, the size of the molecule is specified, the structure is described point by point, and the elements are listed according to their place in the compound. If the structural formula is incomplete, the portion so far known is coded. The system for doing this and translating the information into code notches to allow selection is so simple that it can be learned in thirty minutes. Information other than chemical structure, such as color, physical properties, biological action, patent data, or uses, can be put on the same card.

"When used in chemical-biological screening," Mr. Mooers explained, "the new finding method should result in accelerating the discovery of useful properties of chemicals. Such screening has in the past resulted in new antimalarial drugs, ANTU (rat-killing chemical), and BAL (antidote for mercury poisoning)."

Correlation between the spectrum lines of a compound and its chemical structure should also be facilitated by the Zator method.

A sorting box of uncomplicated design is used to select the combinations of information desired. Out of a thousand cards, for instance, it is possible, in one case to select the ten compounds containing an amine attached to some aliphatic group in five minutes.

Billions of Barrels of Oil in Shale of Naval Oil Reserves in Colorado.—A comprehensive study of the oil shale beds cropping out in Naval Oil Shale Reserves 1 and 3, Garfield County, Colorado, reveals a vast potential reserve of oil larger than hitherto believed present, Director W. E. Wrather of the U. S. Geological Survey announced recently.

The study, made by the Geological Survey in cooperation with the Department of the Navy, Office of Petroleum and Oil Shale Reserves, shows the geology of an area northwest of Rifle, Colo., covering approximately 175 square miles, of which about 85 square miles is underlain by oil shales ranging from 700 to 1,200 feet thick, averaging 10 to 15 gallons oil yield per ton, and having a total potential yield of about 40 billion barrels of oil. A thinner rich unit within the same oil shale sequence ranges from 70 to 135 feet in thickness, yields an average of 25 to 30 gallons of oil per ton, and has a total potential yield of about 10 billion barrels of oil. Approximately one-half of the shale oil resources considered in the report lies in the Naval Reserves. The area covered by the map is only a small part of the total area underlain by the oil shales of the Green River formation which is widespread in Colorado, Utah, and Wyoming.

Chemical Polishing of Aluminum.—Aluminum tubing, pipe and round rod of machinable grades (61ST, 17ST, 24ST, 11ST, etc.) that have been centerless ground with suitable grit (about No. 500) can now be made mirror bright, *without mechanical polishing or buffing.*

This is accomplished by Chemical-Polishing (non-electrolytic) by means of a dip for a few seconds into a specially formulated acid solution.

Centerless-ground aluminum which has been treated thus (by Chemical-Polishing) is further enhanced as follows: (1) Its surfaces are passivated. (2) When subsequently anodized, the surfaces *remain* bright. (3) When subsequently anodized and colored (as with organic dyes) beautiful reflective colors are possible. No lacquers, waxes or after-buffing is required. (4) Striking resemblances to polished and buffed gold, silver, copper, brass, bronze, nickel, chromium, platinum, rhodium and other metals and alloys can be achieved. No lacquers, waxes or after buffing are required. (5) When subsequently chemically (non-electrolytic) oxidized, bright and protected natural aluminum surfaces result. No lacquers, waxes or after-buffing are required.

Aluminum tubing, pipe and rod can be chemically-polished prior to fabrication or machining, but it is preferable to perform this treatment after machining operations.

Chemical-Polishing can be set up in manufacturers and fabricators plants. Costs of chemical polishing are far less than mechanical polishing and buffing. Volume per hour is only limited by the size of tanks. Investment versus a bank of polishing machines is much less, and the resultant product is better.

In the meantime, manufacturers or fabricators who are interested may have their products processed in production in the Philadelphia plant (Technical Processes Division of Colonial Alloys Co.) or they may set up a pilot plant prior to their own production.

They are invited to submit specimens of their work, which will be chemically polished, or chemically polished and anodized or chemically polished, anodized and colored, in accordance with their specifications, at no cost.

Warplane Engine Idea Cuts Radio Tube Weight More Than Half.—By adapting an idea that lightened warplane engines, Westinghouse engineers have cut the weight of a giant radio broadcasting tube 56 per cent.

The success of aluminum cooling fins for aircraft engine cylinders suggested their tryout in the radiators of transmitting tubes. As a result, 25,000-watt tubes with laboratory-built aluminum radiators weigh only 98 lb. instead of the conventional 225-lb. tubes with copper radiators.

An even greater weight reduction, 59 per cent, was achieved when the aluminum radiator was fitted to a 10,000-watt transmitting tube; the combined tube and radiator weight was cut from 44 to 18 lb.

Lightweight radiators of aluminum cut shipping costs and permit tube installation in the close quarters of a radio transmitter by one man instead of two men or one man and a crane. Radiator appearance is improved because the fresh aluminum color is retained.

Aluminum tube radiators were made feasible by an aluminum-to-steel molecular bonding process developed during the war by the Al-Fin Division of the Fairchild Engine and Airplane Corporation. Previous designs failed, Hampton J. Dailey, Westinghouse tube development engineer explained, because the fast oxidizing rate of aluminum rendered the soldering of aluminum directly to the copper anode impractical.

This obstacle was cleared by a metallic "middleman," a hollow steel core that surrounds the copper anode, and is soldered easily to it. A muff of aluminum is cast and bonded to the steel. The 140 aluminum radiator fins are brazed to this muff, fanning out like a tissue paper Christmas bell. The chemically bonded aluminum-to-steel junction offers no measurable resistance to the transfer of heat from the tube anode, thus the advantages of the very high heat conductivity of aluminum and an efficient fin design can be realized fully.

The broadcast tube radiator posed a new problem for the bonding technique. In airplane engine cylinders, Mr. Dailey explained, a thin layer or muff of aluminum is bonded around a thick steel cylinder liner and the pure aluminum of low yield strength but high ductility conforms to the steel of high tensile strength without breaking the bond. The tube radiator, on the other hand, involves a thick shell of aluminum and a thin steel core; the difference in the expansion rates of the two metals in normal service would ordinarily cause failure of the aluminum-to-steel bond. In cooperation with Al-Fin engineers, a new technique was developed whereby the aluminum muff bonded to the steel liner is cooled in such a way as to pre-load the steel in compression so that the bond can withstand the severe thermal cycles experienced in normal use.

Additional field tests are necessary before aluminum radiator tubes can be made commercially available, Mr. Dailey said.

Dry Printing (*Science Illustrated*, Vol. 4, No. 2).—Xerography is the spectacular new invention which adds a fourth to the existing three methods of printing. Dry printing (from *xeros*, dry) is an enormous advance over Gutenberg's type casting of 1450. It substitutes powder for ink, static electricity for pressure and a surface charge for engraved or raised printing faces. With an ordinary camera you can have your "Xerograph" taken and printed in less

than a minute on any reasonably smooth surface such as metal, cloth or ceramics. For office duplicating, it will provide a 7,000-volt machine that can be operated safely by a stenographer. For high-speed printing, lightweight Xeropresses will turn out 1,200 ft. a minute, as fast as any conventional press now running. Photographers will be able to make full color prints in one tenth the present time.

The inventor, Chester Carlson, conceived of dry printing simply as an easy means of small-scale duplicating. Exactly 10 years after his first print, Battelle Memorial Institute (Columbus, Ohio) and the Haloid Co. (Rochester, N. Y.) revealed spectacular applications in every phase of graphic arts.

The method is simple: A layer of photoconductive material (sulfur) on a zinc plate is given a charge of static electricity. This plate is then exposed to a light source which passes through the "copy." Powder sprinkled on the resulting photoelectric image becomes charged only on the spots which the light did not touch. This powder image is then fused to the surface to be printed. While the process is still in the initial stages, there is no doubt that Xerography has a tremendous future in store.

Solar House-warming (*Discovery*, December, 1948).—A woman physicist, Dr. Maria Telkes of the Massachusetts Institute of Technology, has announced that as far as she was concerned harnessing solar energy was practical, and that within a few weeks she would move into a house whose sole source of heat would be derived from the sun. At a cost of $20,000, of which $3000 was for the solar heating plant, the five-room one-story house will be completed in Dover, a town fifteen miles from Boston.

The heating will be built into the roof of the privately financed structure, consisting of 800 square feet of black metal sheeting behind two glass plates acting as heat traps. Ducts circulate the air behind the metal sheets and when warmed is conducted to 'heat-bins' at strategic points throughout the house. The bins are connected to registers, each serving two rooms. Warm air is blown from the bins through the registers into the rooms.

Storage of heat in the bins is accomplished by utilizing a chemical—sodium sulfate dekahydrate—which melts as the heat is stored in it. When the chemical solidifies again, the heat is given off. Heat can be stored for as long as ten days, making possible comfortable warmth even on days when sun rays are not available. The heating system costs nothing to operate, and the chemical lasts indefinitely. When questioned as to what she would do if the solar heating plant broke down during the winter, and if a conventional heating plant would be installed "just in case," Dr. Telkes said emphatically that she would rely solely on her solar furnace and if it broke down she would shiver, "and it will serve me right."

Smoke Tester (*Instruments*, Vol. 21, No. 12).—New hand-operated "Truespot" smoke tester is primarily for use in checking oil burners for clean firing. Smoke test is made by locking paper test disk into instrument, inserting metal probe into suitable hole in smoke pipe, and drawing with six pump strokes a sample of combustion gases from furnace flue. Disk turns light to dark gray depending on smokiness of flame. Soot content is measured by comparing discoloration with nine shadings on scale supplied with instrument. Scale

tells limits of permissible smoke for various burners and types of heating systems.—*Bacharach Industrial Instrument Co.*, 7000 Bennett St., Pittsburgh 8, Penna.

Radar for Tilbury-Gravesend Ferry Service (*British Science News*, Vol. 2, No. 13).—British Railways (London Midland Region) are installing radar at Tilbury so that a better ferry service can be provided in foggy weather. The apparatus is being fitted in Riverside Station, where a picture of the river and its shipping gathered by a revolving scanner above the clock tower, will be recorded on an indicator screen situated in a darkened control room.

An operator watching the screen will use a wireless telephone to advise the masters of the ferry steamers where they are in relation to other vessels and, of course, how they are placed in relation to the ferry landings.

This system of control leaves the masters free to concentrate on their navigation while hearing a brief running commentary from a loud-speaker at their elbow, advising them of their progress. It would not be so simple if they had to study their own indicator screens on board the vessels. The operators of the radar will be drawn from the masters and mates, and will therefore be familiar with the job to be done and able to work in perfect harmony with the men on the bridges of the steamers.

Raman to Continue Research on Diamonds.—Research on diamonds and crystals will be continued by the Nobel prize-winning Indian scientist, C. V. Raman, as he hopes to discover something very fundamental regarding the structure and properties of matter.

Thanks to a remark made lightheartedly at a London University meeting a few years ago, some people believe that he is working on how to manufacture synthetic diamonds. But the Indian scientist discounts such a belief and he categorically denied it at a press conference in Washington last July.

The remark which spread the false belief was: "If diamonds became cheap enough and you could make a nice teapot from them it would be better than Pyrex glass because diamonds conduct heat better. It would be an ideal substitute for cooking vessels."

Raman's interest in diamonds, which began in 1933, is purely scientific. Speaking to the Royal Asiatic Society at Bombay on February 5, he expressed confidence that through his researches on diamonds he would discover more interesting facts about the behavior of molecules in complex systems and compounds.

Past Work.

Raman's many investigations have exploded several text book theories on the structure of solids with particular reference to diamonds. For example, in the past it was supposed that most diamonds were opaque in ultra-violet beyond 3,000 Angstrom, but the results achieved by Raman showed that if the diamond plate was made sufficiently thin, the transmission limit went down to 2,500 Angstrom which was the same as for the less common variety of diamond.

He has also proved wrong the older views which sought to force the spectroscopic picture of crystal behavior into a pattern similar to that of its elastic vibrations. His theory is that vibrations both in the acoustic and optical

ranges of frequencies, instead of yielding continuous spectra, appear as a set of modes with sharply defined monochromatic frequencies.

Raman has founded his own research institute at Bangalore where he will continue his researches.

High-Altitude Meteorological Research Station to be Set up in the Himalayan Ranges.—A party of Indian scientists will survey the western Himalayan ranges, including the 17,000-ft. Bara Lacha Pass, in April this year. The object of the survey is to select a site for a high altitude meteorological research station.

The Director-General of Observatories of India, Dr. S. K. Banerji, said in Bombay on February 7 that the Government had prepared an eight-year plan to set up a research station at a cost of $900,000.

Explaining the Government's other plans to improve the scope of present Indian observatories, Banerji said the Kodaikanal Astronomical Observatory (South India) would shortly be equipped with a modern type of ionospheric recorder to study the changes taking place on the surface of the sun. Two special types of very sensitive seismographs had been acquired from the United States. These would record minute tremors known as "micro-seisms" produced by cyclones in the Bay of Bengal and in the Arabian Sea. Records of micro-seisms would make it possible to get directions of a storm center, thus facilitating warnings to ports and ships of any cyclone. One of the seismographs has been fitted at the Poona Observatory and the other at the Madras Observatory.

The Meteorological Department proposes to set up a field magnetic observatory near Bombay. Negotiations are in progress between the Central Government and the Bombay Government regarding the location of this observatory in the reserve forest, 35 miles south-east of Bombay.

Nuclear Research Projects for All India Concentrated at Tata Institute, Bombay.—At the Tata Institute of Fundamental Research in Bombay, which has been made the center for all large-scale projects in nuclear research in India, a team of scientists is receiving training in experimental and theoretical techniques of nuclear research under the guidance of Dr. H. J. Bhabha, recently awarded the Hopkins Prize of the Cambridge Philosophical Society for his investigations on the theory of elementary atomic particles.

Important work is being done at the Institute in the application of photographic technique in nuclear research, construction of portable instruments for geological prospecting of radio-active minerals, measurement of the intensity of cosmic radiation at high altitudes with radiosonde technique, ground experiments of mesons with the Wilson chamber and measurement of azimuthal effect of cosmic radiation.

The scheme for high-altitude measurements of cosmic radiation with radiosonde technique envisages a series of 32 flights at four stations of widely different latitudes and will extend over two or three years.

Among the visiting professors at the Institute this year was Prof. M. S. Vallarta of Mexico University, who participated in all research activities of the Institute. The Government of India has sanctioned financial assistance to the Institute for increasing its educational facilities.